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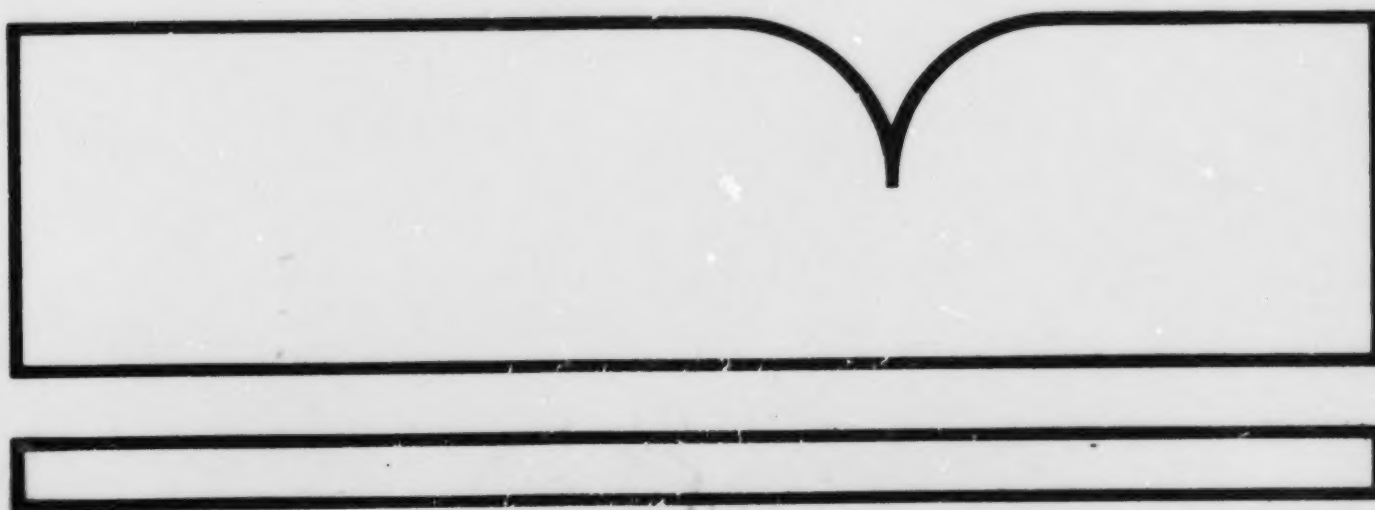
Technical Assistance Document: Quality Assurance
Guideline for Process Feed Rate Monitors in the
Portland Cement and Lime Industries

Engineering-Science, Inc.
Durham, NC

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Environmental Monitoring and Support Lab.
Research Triangle Park, NC

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Robin R. Segall, et al

Engineering-Science
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TECHNICAL ASSISTANCE DOCUMENT
QUALITY ASSURANCE GUIDELINE
FOR PROCESS FEED RATE MONITORS
IN THE PORTLAND CEMENT AND LIME INDUSTRIES

by

Robin R. Segall
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Contract No. 68-01-6312

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16. ABSTRACT This study, sponsored by the Quality Assurance Division of the U.S. Environmental Protection Agency's Environmental Monitoring Systems Laboratory, evaluated the performance of process feed rate monitors used in the Portland Cement and Lime Industries. Particulate emission regulations applicable to both industries are specified as kilograms of particulate per megagram of feed to the process. Regulatory agencies have assumed that feed rate monitors are highly accurate due to process control considerations; this study evaluated the validity of this assumption. This study has found that six major types of feed monitors are currently used in the Portland Cement and Lime Industries. Each of these monitor types are reliable and accurate; seldom do the errors exceed +3 percent, and in most cases the monitor performance allows control of the process flows to within +1 percent. This performance level is necessary (1) to ensure that the resulting products meet specifications, and (2) to minimize kiln and calciner operating problems. Operating personnel routinely check the operation of the feed rate monitors and calibration is carried out frequently. In the majority of cases, regulatory agencies could assume that the process feed rate monitors are sufficiently accurate. However, if some question should arise concerning the monitors, the evaluation procedures listed in this report may be used to verify accuracy.		
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FOREWORD

Measurement and monitor research efforts are designed to anticipate potential environmental problems, to support regulatory actions by developing an in-depth understanding of the nature and processes that impact health and the ecology, to provide innovative means of monitoring compliance with regulations, and to evaluate the effectiveness of health and environmental protection efforts through the monitoring of long-term trends. The Environmental Monitoring Systems Laboratory, Research Triangle Park, North Carolina, has responsibility for: assessment of environmental monitoring technology and systems; implementation of agency-wide quality assurance programs for air pollution measurement systems; and supplying technical support to other groups in the Agency including the Office of Air, Noise and Radiation, the Office of Toxic Substances, and the Office of Enforcement.

This report describes quality assurance procedures applicable to mass feed rate monitors in the cement and lime industries. The report is intended for inspectors who may need to assess the performance of these systems in a number of different plant locations.

Thomas R. Hauser, Ph.D.
Director
Environmental Monitoring Systems Laboratory
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ABSTRACT

This study, sponsored by the Quality Assurance Division of the U.S. Environmental Protection Agency's Environmental Monitoring Systems Laboratory, evaluated the performance of process feed rate monitors used in the Portland Cement and Lime Industries. Particulate emission regulations applicable to both industries are specified as kilograms of particulate per megagram of feed to the process. Regulatory agencies have assumed that feed rate monitors are highly accurate due to process control considerations; this study evaluated the validity of this assumption.

This study has found that six major types of feed rate monitors are currently used in the Portland Cement and Lime Industries. Each of these monitor types are reliable and accurate; seldom do the errors exceed ± 3 percent, and in most cases the monitor performance allows control of the process flows to within ± 1 percent. This performance level is necessary (1) to ensure that the resulting products meet specifications, and (2) to minimize kiln and calciner operating problems. Operating personnel routinely check the operation of the feed rate monitors and calibration is carried out frequently.

In the majority of cases, regulatory agencies could assume that the process feed rate monitors are sufficiently accurate. However, if some question should arise concerning the monitors, the evaluation procedures listed in this report may be used to verify accuracy. The following material also includes a summary of typical problems and calibration techniques associated with the monitors.

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1.0 INTRODUCTION

The New Source Performance Standards (NSPS) and many State Implementation Plan (SIP) regulations contain several emission rate limits specified per process operating rate, as shown below:

$$\frac{\text{Pollutant emission rate}}{\text{Process operating rate}}$$

In the NSPS, this type of emission standard is found in Subparts F and HH, which contain the Standards of Performance for Portland Cement Plants and Lime Manufacturing Plants, respectively.^{1,2} In these two subparts, the allowable emission limits for particulate matter are expressed per unit of process weight, as indicated by the following:

Portland Cement Plants (Subpart F)

0.15 Kg per metric ton of feed (dry basis) to the kiln

Lime Manufacturing (Subpart HH)

0.15 Kg per megagram of limestone feed [to the rotary kiln]

0.075 Kg per megagram of lime feed [to the lime hydrator]

In the past, a substantial effort has been directed towards the quality assurance (QA) of the numerator in these expressions, while the accuracy of the denominator remained unquestioned. For process control reasons, agencies have routinely assumed the denominator is accurate.

Subpart F, which deals with portland cement plants, specifies that the owner or operator shall record the daily production rates and the kiln feed rates (see Section 60.63). However, it does not specify how these rates are to be measured, nor to what degree of accuracy.* Section 60.64 (Test methods and procedures) further specifies that total kiln feed rate shall be determined during testing by suitable methods, and shall be confirmed by a material balance over the production system.

* Although the NSPS specify that the kiln feed rate be monitored, information may be available on clinker production rate and cement production rate. Appendix A discusses the calculations involved in converting from production rate to kiln feed rate.

On the other hand, Subpart HH on lime manufacturing, is more specific in its stipulations concerning process monitoring. Section 60.343 directs the owner or operator to conduct a performance test by installing, calibrating, maintaining, and operating a device to measure (1) the mass rate of limestone feed to any affected rotary kiln and (2) the mass rate of lime feed to any affected lime hydrator. Further, these devices must be accurate to within ± 5 percent of the mass rate over this operating range.

Despite the more rigorous requirements for process monitors outlined in Subpart HH, little attention has been paid to the QA procedures for these instruments, including operation, maintenance, and calibration. Data from process monitors, which are reported to EPA and state air pollution control agencies, establish whether a source is in compliance, therefore the quality of this data is important. Errors which might lead to a positive bias in mass measurements by these instruments would present a special concern, since an artificial increase in the denominator of the emission limit would allow for a real, but inappropriate, increase in the allowable emission rate.

This report examines the information available on the accuracy and reliability of data from these monitors. In addition to the current literature, equipment vendors and plant operators were consulted to obtain information concerning types and applications of these monitors, reported accuracy, sources of error, operation and maintenance procedures, calibration procedures, and general evaluation procedures. This report includes an introductory section that discusses the types and typical locations of process feed rate monitors for the portland cement and lime industries. The operation and routine calibration of each of the major types of monitors typical of these industries are described in section 3.0. This section also addresses the quality assurance aspects of each type of monitor including accuracies, typical errors and problems, preventive maintenance, and visual evaluation techniques.

2.0 TYPES OF FEED RATE MONITORS USED IN THE PORTLAND CEMENT AND LIME INDUSTRIES

The types of feed rate monitors used in the portland cement and lime industries are diverse, due to the wide variety of specific processes being used. The cement and lime industries have been evolving rapidly in response to rising fuel costs; these developments have had an impact on the types of monitoring instruments in use. Because of the nature of the materials handled, wet and dry process cement plants must be discussed separately. A complete description of the basic cement and lime processes has not been included here, since this information is available in numerous EPA publications and commercial articles.

2.1 WET PROCESS CEMENT MILLS

Wet process cement mills are responsible for approximately 50 percent of the portland cement produced in the United States.³ Most of the existing mills are between 5 and 30 years old; no new plants have been built since 1978. Only a few wet process mills were built after 1972, since the energy requirements for these plants are much greater than requirements for dry process techniques.

While the design of wet process mills depends heavily on the types and sources of raw materials used, there are components common to most existing plants, as indicated by the simplified flow charts presented in Figures 2.1-1 and 2.1-2. (Only components of interest to this report are included in the charts.) As seen in Figure 2.1-1, several storage tanks contain blended slurry mix, which consists of the various raw materials in the proportions necessary for producing the type of portland cement desired. Slurry is pumped from these tanks on a continuous basis; and at a rate which must be synchronized carefully with the kiln rotational rate. Located downstream of the slurry pump is a feed rate monitor that controls the slurry pump; this instrument is of special interest to regulatory agencies, since it provides the

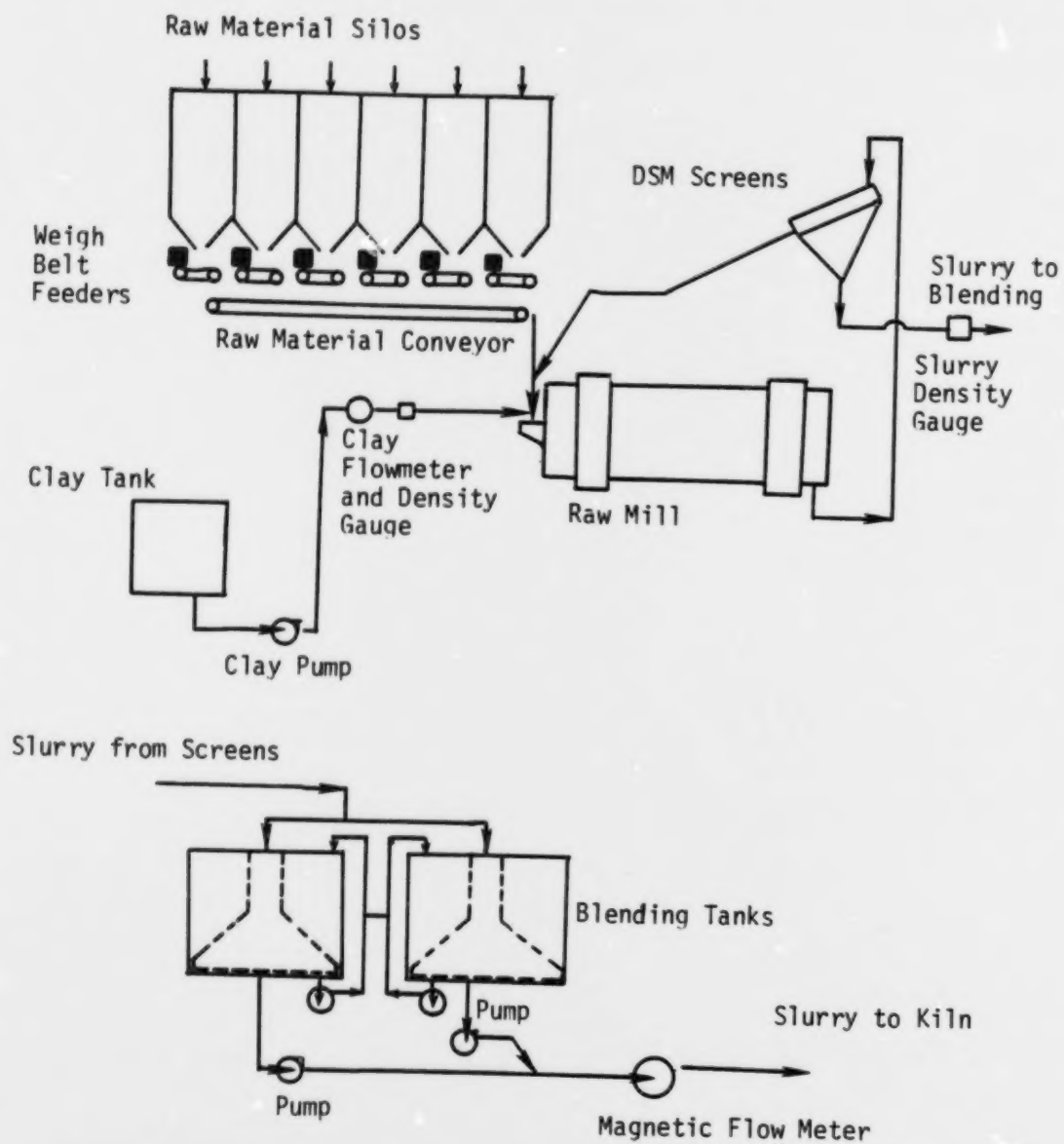


Figure 2.1-1. Wet process cement mill flowchart: slurry preparation.

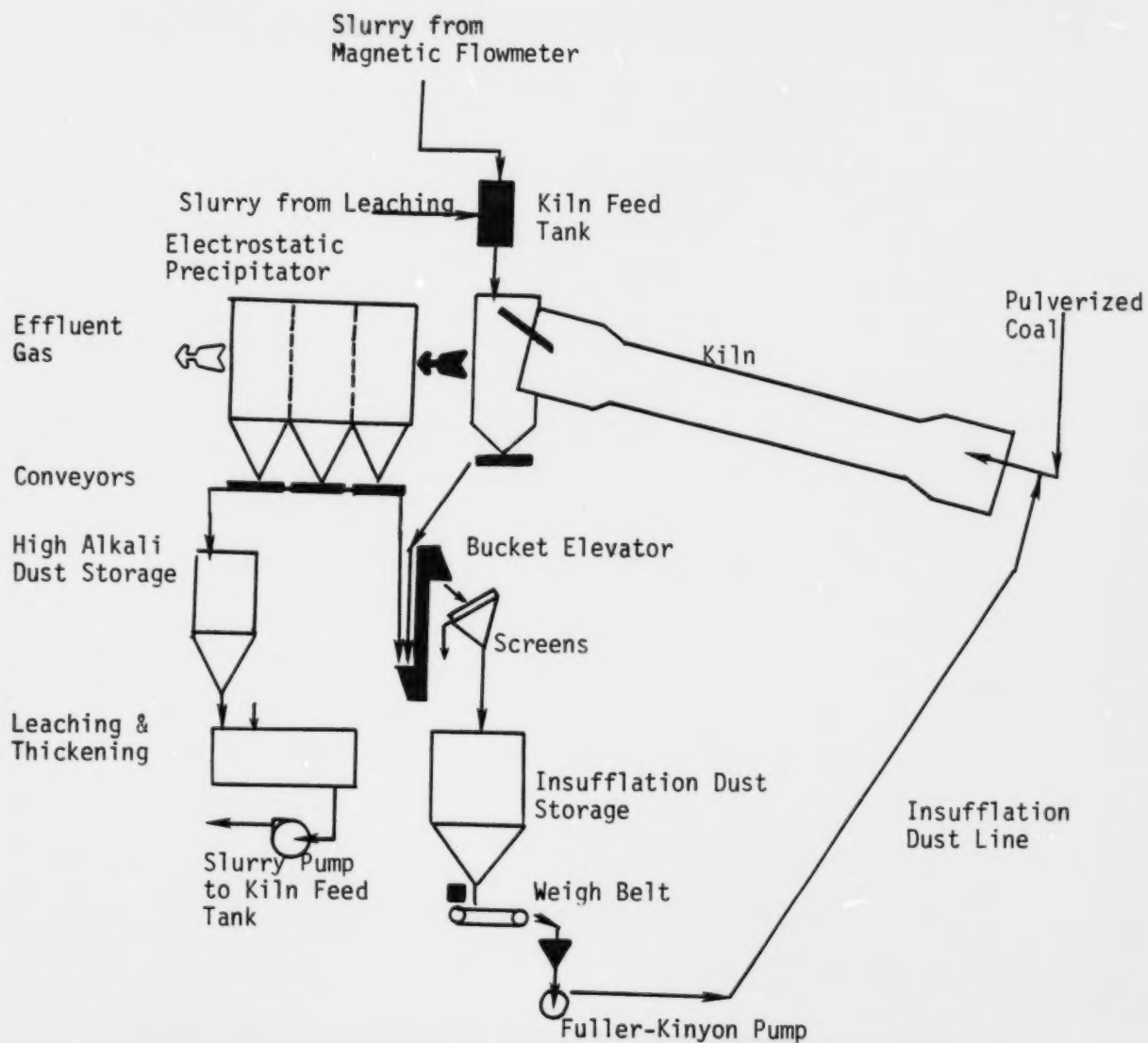


Figure 2.1-2. Wet process cement mill flowchart: kiln dust return.

mass flow rate of the main kiln feed line. In the majority of wet process plants for which information is available, this instrument is a magnetic flow meter.⁴⁻¹⁴ One of the nine plants for which information is available uses a ferris wheel feeder to obtain this mass flow rate.¹⁵ Since both of these instruments provide a volumetric measure of the flow rate, it would, theoretically, seem necessary to know the slurry density before calculating the feed rate of dry solids to the kiln. In actuality, the slurry must be carefully maintained at a specific density, which may vary from 33 percent water, to 36 percent water from plant to plant.⁴⁻¹⁵ Only one of the nine wet process mills included a liquid density gauge on the main slurry line to the kiln.⁴

Kiln dust collected by air pollution control devices is usually recycled to the greatest extent possible, since this represents a significant amount of material. This partially calcined material often requires only a little additional pyroprocessing for conversion to clinker material. The degree to which kiln dust can be recycled is limited primarily by its alkali content. In wet process plants, the collected dust can either be (1) returned in a dry state to the burner side of the kiln for insufflation*, or (2) leached to remove alkali, then returned to the feed side of the kiln.¹⁶ Material from the cyclones (immediately following the kiln) and dust from the first field of the electrostatic precipitator (the most common type of dust collector at wet plants) often can be recycled without pretreatment. The dust is conveyed to a storage hopper, where it is screened, then fed to a Fuller-Kinyon® pneumatic pump (see Figure 2.1-2), which delivers the material to a coal burner pipe. Some plants use a weigh belt feeder to monitor and control the feed rate to the pneumatic pump.^{4,14,16} Since the dust does not return to the raw material circuit (shown in Figure 2.1-1), the main slurry feed monitor would not measure this material. The quantity of insufflated dust could be as much as 10 percent of the total dry solids kiln feed; however, in most cases it is less than 5 percent. Plants not using a weigh belt feeder to monitor the return line may instead have a rotary feeder or screw feeder, both of which would provide only an approximate measure of the mass flow rate.^{9,16}

*Insufflation, in this context, refers to the reintroduction by blowing of partially calcined raw materials (dust) into the kiln near the burner.

The collected dust with high alkali content must be leached prior to recycling. The treated material is thickened, then pumped to the feed side of the kiln as illustrated in Figure 2.1-2. At this point, recycled slurry would not be included in measurements made by the main slurry feed rate monitor. The quantity of leach circuit return could be as much as 1 to 3 percent of the total kiln feed. Based on the limited information available, these lines are usually not equipped with flow gauges.

Several other mass flow rate monitors are commonly used in wet process cement plants. Individual weigh belt feeders are located under each of the raw material silos to ensure the proper proportion of materials in the raw mill feed⁴⁻¹⁵ (see Figure 2.1-1). The clay is stored in a separate tank and metered to the raw mill through a series of valves and pumps controlled by a magnetic flow meter and a liquid density instrument. (One plant used a ferris wheel feeder in this capacity.¹¹) The raw mill output is sent to a set of screens; any oversize material from these screens is sent back through the raw mill while the remaining material is sent to a set of storage tanks, as illustrated at the bottom of Figure 2.1-1. The ground material in these tanks has a fineness of 95 percent passing through 50 mesh, and a water content of 33 to 36 percent.⁴⁻¹⁵ Prior to the storage tanks is a liquid density gauge that maintains the desired liquid density by controlling the rate of trim water. Theoretically, the accuracy of the main feed rate monitors could be checked roughly by totaling the individual feed rates of the various components to the raw mill. This would be difficult, however, without a thorough understanding of the specific plant material flowchart. The simplified flowcharts used here do not indicate the numerous points where water is added and where small material losses occur.

2.2 DRY PROCESS CEMENT PLANTS

Numerous process feed rate monitors are used in dry process plants to monitor and control the flow of materials. A partial list of applications includes the following:

- (1) Monitor flow of crushed materials to raw material silos and to storage piles.
- (2) Proportion and feed raw materials to raw grinding mills.

- (3) Control feed rate of homogenized material to kiln.
- (4) Control feed of recycled kiln dust from dust collectors to various points in the process.
- (5) Proportion and feed clinker, gypsum, and fly ash to finish mills.
- (6) Monitor flow of cement to storage silos.
- (7) Control feed rate of coal to pulverizers.

The instrument system of interest to regulatory agencies includes the monitor for homogenized feed to the kiln, as well as any monitors for the recycled kiln dust. As is the case with wet process plants, the kiln feed rate and the chemical/physical properties of the kiln feed must be carefully controlled to ensure that the clinker produced will meet necessary specifications.^{17,19} If a plant allowed the monitors used in applications 2, 3, 5 and 7 (listed above) to be in error by more than 1 to 3 percent, the economic consequences could be serious. Specifications for new monitors usually demand an accuracy of ± 0.5 percent, requiring that plant operations personnel be highly skilled in calibration techniques and maintenance procedures.

Numerous variations exist in the process design, especially regarding the raw mill circuit, the type of kiln and preheater/precalciner, and the type of clinker cooler. While there is no "typical" dry process plant, the simplified process flowchart presented in Figure 2.2-1 illustrates one common approach (only components of direct interest to this report are included).

As Figure 2.2-1 illustrates, raw materials are stored in a set of silos; under each silo is a weigh belt feeder²⁰⁻²⁶ which can be adjusted on an hourly basis to ensure the proper proportions of raw material. Material discharged from the various weigh belt feeders is collected on a large belt conveyor which transports the material either to the raw mill air separator, as shown in Figure 2.2-1, or directly to the raw mill itself. One plant uses a weigh scale on this conveyor to directly obtain a total raw mill feed rate.²⁷ The raw materials are ground and dried in the raw mill circuit. The resulting raw meal* has a fineness of 75 to 90 percent through 200 mesh, and a moisture content of 0.5 to 1.0 percent.²⁰⁻²⁶

* Coarsely ground and homogenized raw materials as feed to the kiln, otherwise known as kiln feed.

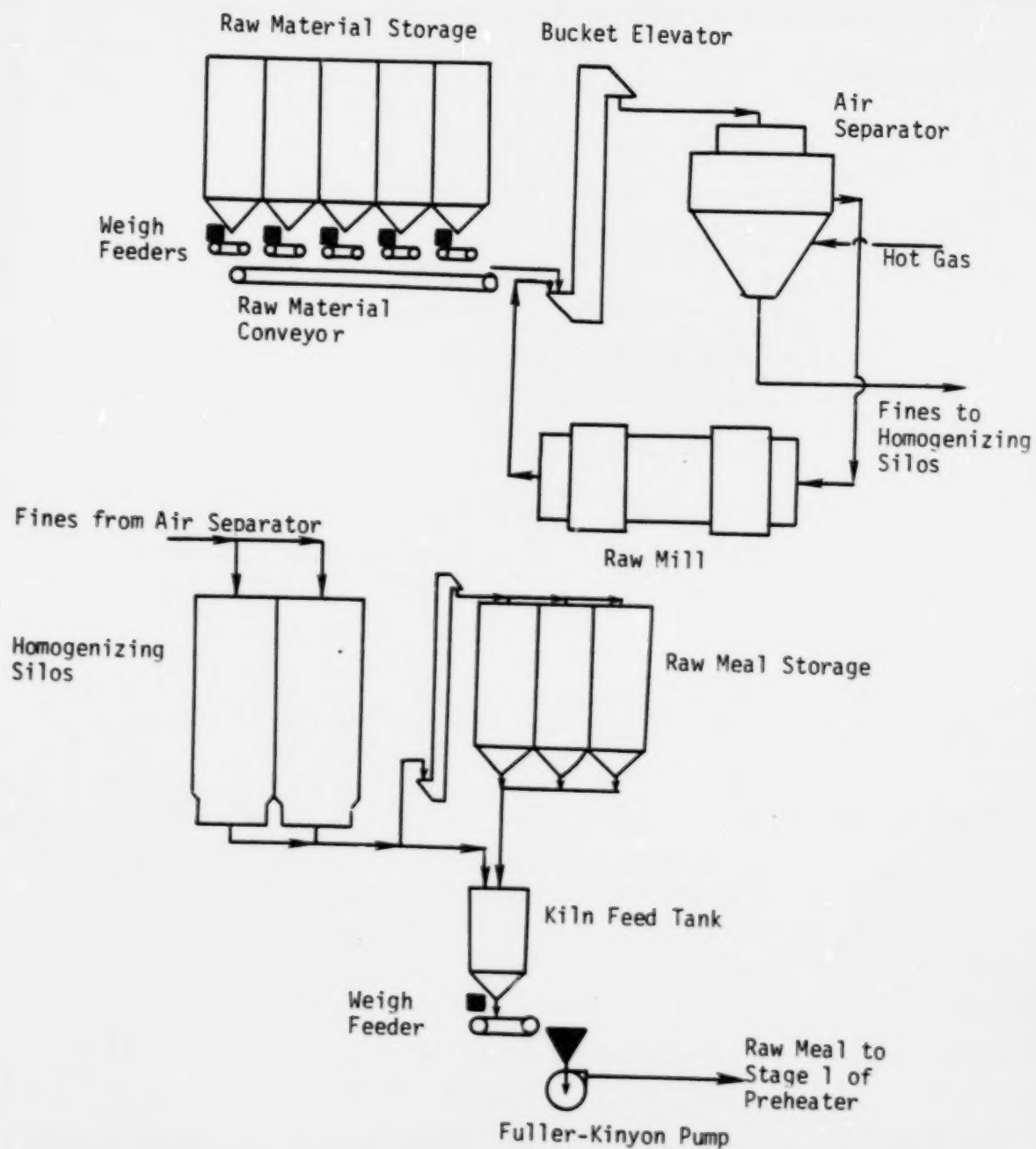


Figure 2.2-1. Dry process cement mill flowchart: raw meal preparation.

The raw meal is transported to a set of two homogenizing silos, which are agitated to ensure thorough mixing of the materials. The raw meal may then either be fed directly to the kiln feed tank, or sent to a set of storage silos. A feed rate monitor is used below the kiln feed tank. As in the wet process plants, one function of this monitor is to ensure that the operators are able to match the kiln feed rate with the kiln rotational speed. After leaving the kiln feed tank, the raw meal is transported to the top of the preheater tower by either a pneumatic pump or a Polysius® vertical conveyor. Instruments used to monitor the kiln feed rate include: weigh belt feeders, impaction plates, nuclear sensors, and pneumatic conveyor pressure sensors.²⁰⁻²⁸ Available information indicates that the most common type of instrument appears to be the weigh belt feeder,²⁰⁻²⁶ although the impaction plate sensor may be gaining favor for new plants, according to one major cement plant design/ construction firm.⁴⁸ Polysius is recommending the pneumatic conveyor pressure sensor and has installed this type of monitor in five U.S. plants.²⁹

The recycled kiln dust is either returned directly to the kiln for insufflation, or transported back to various points in the raw meal preparation area. Flow rate of the insufflated material can be measured by the same manner used in wet process plants. The most common instruments used to obtain these measurements appear to be rotary feeders, screw feeders, and weigh belt feeders,^{16,25} all of which control the flow of dust to pneumatic pumps which then transport the dust to the kiln burner tubes. The recycled dust may also be returned to the kiln feed tank or back to the raw mill circuit. In either case, the flow of this material would be included as total kiln feed, since the feed rate monitor is located just before the kiln preheater. The quantity of recycled kiln dust is normally less than 10 percent of kiln feed, although in extreme cases it could reach 20 percent.

The performance of the kiln feed rate monitor can be checked roughly by totaling the various raw material flow streams into the raw mill circuit.* To accomplish this, the moisture levels of each stream must be considered, since substantial drying occurs in the raw mill circuit.

* See Appendix A for relevant information.

Modest dust losses occurring in the raw meal preparation area must also be taken into account. For these reasons, checking monitor performance by this method is time consuming, and is subject to substantial error unless agency personnel are very familiar with the specific plant flowchart and have data on the characteristics of the material flow streams. (Operating personnel have used this approach as a general check on the monitor performance.^{19,27})

2.3 LIME PLANTS

Lime is produced from the calcination of limestone. A variety of kilns are used in limestone production, including vertical kilns, rotary hearths, fluidized-bed kilns, and rotary kilns. The latter are responsible for approximately 80 percent of the domestic lime production.³⁰ Subpart HH of the NSPS requires that the feed rate of limestone to the kiln be measured on a continuous basis with an accuracy of ± 5 percent.² If the plant has a lime hydrator, the feed rate to that must also be measured continuously.

A simplified flowchart of a lime plant with a rotary kiln and preheater is presented in Figure 2.3-1, which illustrates only components of direct interest to this report. Limestone from the quarry is crushed and screened to produce the size of material appropriate for the kiln type. A live stockpile of this limestone, 10 to 30 days capacity, is maintained above one or more reclaiming tunnels. Limestone withdrawn from live storage passes via a conveyor belt to large stone storage bin(s). This material is withdrawn by vibrating feeders and a conveyor transports the material to screens, where the minus 3/8 in. fines generated by limestone attrition is removed. After screening, the material enters the preheater tower directly above the feed end of the kiln. It remains in the preheater for approximately 2 hr. and is discharged to the kiln feed pipes at a temperature in excess of 1,500°F.^{30,34} The kiln feed rate is matched to the rotational speed of the kiln and is controlled by plunger feeders.^{32,34,38,47} The mass feed rate is adjusted by changing the frequency of the plungers and the length of the stroke, which are capable of controlling the feed rate to ± 1 percent of the desired value.⁴⁸

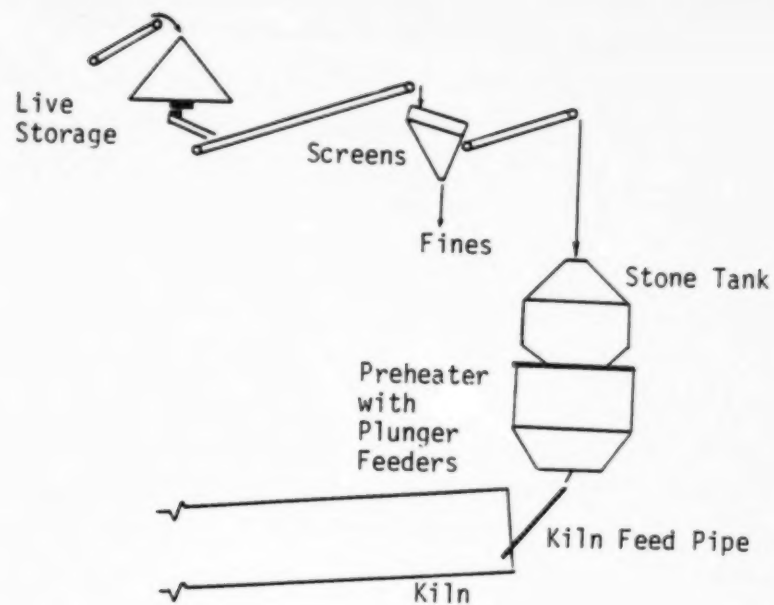


Figure 2.3 -1. Lime plant flowchart #1.

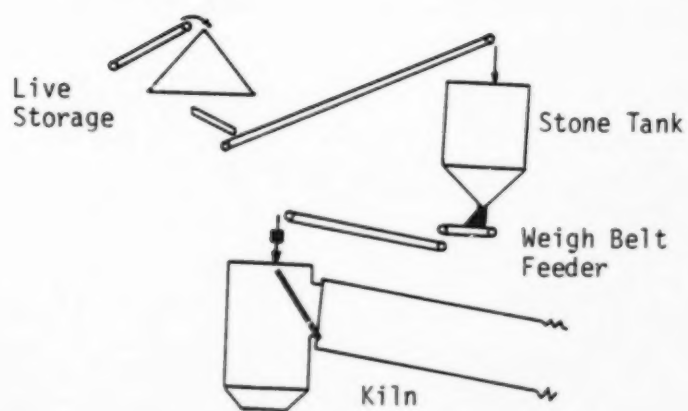


Figure 2.3-2. Lime plant flowchart #2.

Another common type of plant feed system utilizes the same basic components, up to and including the main stone storage bin(s). Following this, a conventional weigh belt feeder is used for monitoring and controlling the kiln feed rate.^{35,40,41,43,45} After the feed rate monitor, the limestone passes via conveyor belts to the feed side of the rotary kiln. A simplified flowchart for this type of plant is illustrated in Figure 2.3-2.

Lime plants having hydrators primarily use weigh belt feeders to control the amount of feed entering the mixer. Since only 10 percent of the lime is processed further to produce hydrated lime,³⁰ a number of plants do not have this equipment. Weigh belt feeders are also used in lime plants for feeding coal to the pulverizers. The majority of rotary kilns in the U.S. are fired with coal.

3.0 OPERATION, CALIBRATION AND EVALUATION OF PROCESS FEED RATE MONITORS

This examination into the use of process feed rate monitors in the Portland cement and lime industries revealed that six main types of monitors are commonly used. These are: (1) the gravimetric weigh belt scale, (2) the gravimetric weigh belt feeder, (3) the nuclear weigh belt scale, (4) the impact flowmeter, (5) the pneumatic weigh feeding system, (6) the plunger-type feeder, and (7) the magnetic flowmeter. This section will examine and discuss in detail each of these monitor types, focusing on their operating principles, expected accuracies, calibration methods, maintenance, typical problems and errors, and checklists for inspector evaluation. The following material should enable EPA personnel and others to reasonably assess process feed rate monitors in conjunction with NSPS performance testing.

Three other process feed rate monitors were mentioned in the literature on cement and lime kiln feed rate monitoring, but none were found to be used to any significant degree in the portland cement and lime industry. Therefore, they are not included in the detailed coverage of this report. However, for reference purposes, these monitors are identified and briefly discussed below:

- (1) Ferris Wheel Feeder - Rotary feeder with buckets of a specified volume; it delivers a specified volume of slurry depending on r.p.m.s. A major manufacturer of these devices is Traylor Engineering, a division of Fuller, Inc.
- (2) Weigh Hoppers⁴⁹ - Material is fed in a batch mode to a small hopper mounted on strain-gauge type load cells. When the desired quantity is in the hopper, the flow is stopped and the material is discharged to the next process step. The quantity of material charged is calculated by totalling the number of cycles and the preset quantity during each cycle. The claimed accuracy is better than +1 percent.
- (3) Loss-in-Weight Feeder⁵⁰ - Components consist of a weigh hopper (on load cells) situated above a feeder, such as a screw feeder or vibrating feeder. When the hopper is first full

(with material from storage bin located above the hopper), the feeder delivers at a rate dependent on the set rate. As it feeds, the decreasing weight of material in the weigh hopper is continuously sensed and compared with a programmed diminishing setpoint which has been established to satisfy the flow rate desired for processing. The deviation between these two signals is used to adjust (increase) the speed of the feeder. When the material in the hopper reaches a preselected low-point, it is quickly refilled, and the cycle repeats.

3.1 GRAVIMETRIC WEIGH BELT SCALES

Gravimetric weigh belt scales are the most basic form of gravimetric continuous-weighing devices. The normal weigh belt scale is part of a material-handling conveyor belt system and supports a portion of the moving conveyor belt. It uses a mechanical lever or load cells to instantaneously weigh the amount of material carried on that portion of the belt. Weigh belt scales are used in both the lime industry and the portland cement industry. When used for kiln monitoring, weigh belt scales usually act as a materials balance check, in conjunction with another weigh feeding device which actually provides the consistent kiln feed rate.

3.1.1 Operating Principles

Figure 3.1-1 illustrates the basic components of a gravimetric belt scale weighing system. In operation, the weigh platform, or weighbridge, senses the instantaneous weight of the material passing over it. This

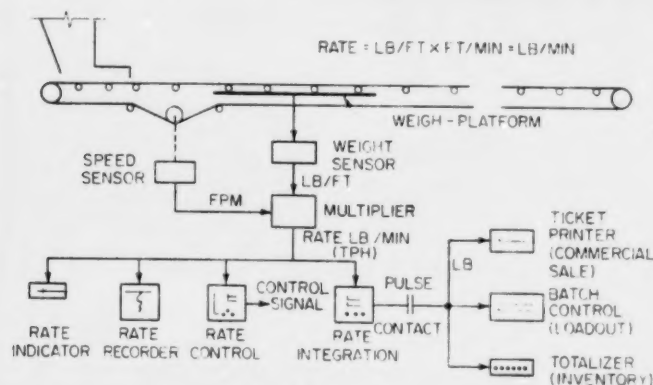


Figure 3.1-1. Gravimetric weigh belt scale.⁵⁰

weigh platform is a frame on which standard conveyor idlers are mounted; the number and configuration of these idlers depend on manufacturer and model (see Figure 3.1-2). Through its suspension, it transmits the true force on the weigh idlers to a load-sensing device. In most recent installations the load-sensing device is composed of one or more linear voltage differential transformer (LVDT) load cells or strain-gauge load cells.⁵¹ Both of these types of load cells generate electrical output signals in proportion to force, while undergoing relatively small deflections under maximum load,⁵¹ as indicated below.

Load cell	Deflection	Output Range
LVDT	0.015 - 0.03 in.	10 millivolts
Strain-gauge	0.008 in.	1 volt

A second sensing device, the belt-speed sensor measures the speed of the conveyor belt. The weight and speed signals are transmitted to a multiplier whose product signal (expressed in units such as lb/min) is integrated or accumulated over a period of time to determine totalized flow which is then displayed by the totalizer (see Figure 3.1-1). The information from the multiplier and integrator can be used for many purposes such as rate control and recordkeeping.

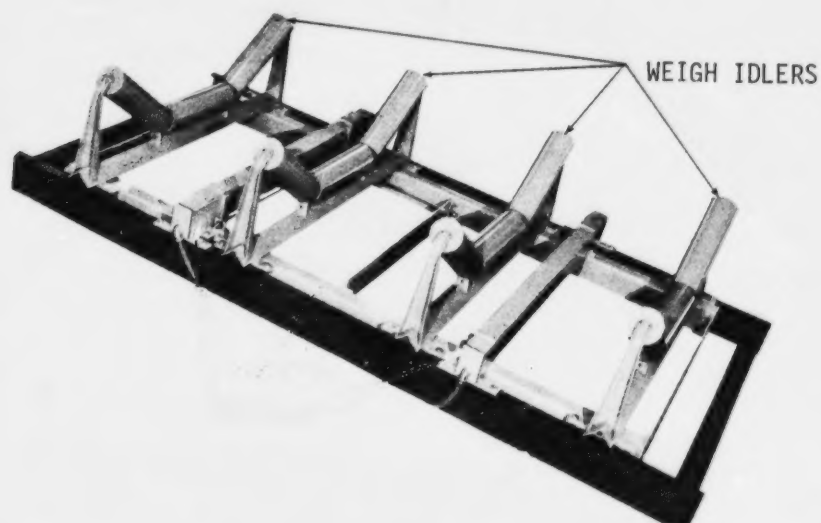


Figure 3.1-2. Ramsey® weigh platform.⁵²

3.1.2 Accuracy

For factory approved installations, manufacturers guarantee load cell-type weigh belt scales to weigh and totalize with an error not to exceed 0.5 percent of full scale,^{53,54} while mechanical type scales may have claimed accuracies of ± 0.25 percent or better.⁵⁰

3.1.3 Calibration

There are three common methods for calibration of gravimetric weigh belt scales. These are: using a material test, using test chains, or using test weights. A fourth method, electronic calibration, is not as commonly seen.^{55,56}

A typical calibration scheme involves use of a material test for initial belt scale calibration upon installation^{18,27} and then use of a test weight or test chain calibration monthly thereafter.²⁷ Evidence that an instrument is performing incorrectly, of course, indicates that a calibration should be performed immediately. The methods and their relative advantages and disadvantages are described below.

3.1.3.1 Material Test

The most accurate method of testing and calibrating a weigh belt scale is to conduct a material test.^{17,57} In a material test, which utilizes the comparison method, the results of a belt scale or feeder weighment are compared with the results of a static scale (usually a track or truck scale). Caution must be taken to prevent any change in material condition (moisture content) or material quantity (from losses due to spillage). Each vehicle used for catching and transporting the material must be weighed carefully to accurately determine its weight when empty.

Although considered the most reliable of the calibration methods, material testing is the least practical and most expensive, as well as very time consuming. Material tests, most often performed when a scale is first installed, may be used to calibrate a test weight; this application is discussed in Section 3.1.3.3. In some cases, material testing may be virtually impossible, due to plant layout and available facilities.

3.1.3.2 Test Chains

Test chains are designed to simulate actual belt loading (in lbs/ft).^{56,57} Roller-chain construction permits the chain to rest on the belt over the weighbridge area while the belt is running empty. Multiplying the number of feet of belt travel by the lbs/ft weight of test chain, produces the true weight readout that should be displayed by the scale totalizer.

3.1.3.3 Test Weights

Using a test weight is the simplest, least time consuming, and least expensive way to calibrate a weigh belt scale.²⁷ To calibrate, the test weight is placed in the test position (this position depends on the manufacturer) with the belt running empty and the function switch in the "off" position. The totalizer reading is then recorded. Next, the function switch is turned to the "calibrate" position, the totalizer advances until the standard test footage is reached, and then stops automatically. The integrated value is compared with the standard value pre-established for the system (probably by using a material test). Finally, the span is adjusted to bring it into tolerance (span is the algebraic difference between the upper and lower range values).

3.1.3.4 Electronic Calibration

Electronic calibration employs a precision wire-wound resistor that is "sized" to simulate the normal load on the belt. The operator records the "before" totalizer reading, and then turns the calibration switch on. After the test footage is reached, the totalizer stops automatically. The difference in recordings is then compared to the calibration value supplied for the system.

3.1.4 Typical Problems, Errors, and Maintenance

This section addresses the various conditions that influence the accuracy of load cell-type weigh belt scales. Because of the nature of the instrument design, they are generally mechanically associated.⁵⁷

Belt tension probably influences weigh belt accuracy more than any other factor.⁵⁰ Thus at all times, the belt tension in the area of the scale must remain constant so that the weighbridge assembly is affected as little as possible. Unfortunately, there are many factors affecting

belt tension, including temperature, location of the scale on the conveyor, idler alignment, and conveyor slope, all of which will be addressed later.

To obtain the best weighing system accuracies, conveyors longer than 40 ft are usually equipped with a constant tension or gravity type take-up*.⁵⁸ If the conveyor is shorter than 40 ft and exposed to changing ambient temperature, or if the conveyor loading is not constant, then the conveyor should also be equipped with constant tension gravity take-ups to enhance system accuracy.⁵⁸ For best results, the gravity take-up should be located near the head pulley, where belt tension is the highest. Maintaining a constant tension at this point assures minimal tension variation at the scale location. Tail section gravity take-ups are undesirable because they tend to impose higher tensions in the area of the scale.⁵⁹ Gravity take-ups help, but do not ensure an even tension on inclined conveyors.⁶⁰

Belt tension can be roughly checked in the following manner: When the belt is running empty, it should run completely in the idler trough. If not, corrections may be made by adjusting the gravity take-up mechanism.⁶¹

Weigh belt scales should be operated with loads that fall between 50 and 90 percent of rated capacity.⁶⁰ As shown in Figure 3.1-3, the "percent error" is at a minimum above 50 percent rated load.⁵⁰ Operating with 90 percent as an upper limit helps prevent misweighing or scale damage that may result from an occasional weigh surge.⁶⁰

For a rough estimate of the minimum normal loading on a scale, square the number that represents the belt width and divide by 50; this gives a value in lbs/ft. As an example for a belt 24 in. wide:
 $24^2 \div 50 = 11.5$ lbs/ft. This is the minimum desired loading for this particular belt. However, the belt scale will weigh accurately with a loading less than 11.5 lbs. If the belt scale is operating with a normal loading of 11.5 lbs/ft the accuracy will be extended over a normal 5-to-1 range, or down to a value of 2.3 lbs/ft.⁵⁸

* Constant tension gravity take-up mechanism - a weight at a roll on the return side of a belt weighing system used to maintain belt tension.

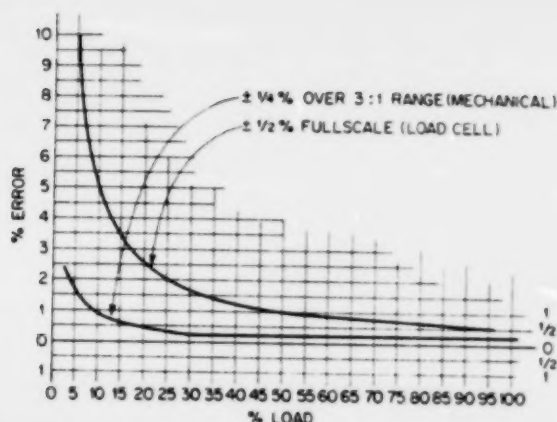


Figure 3.1-3. Percent error vs. percent load for weigh belt scales.⁵⁰

As mentioned previously, it is important to avoid overloading a weigh belt scale. Scales that use strain-gauge load cells are especially vulnerable to damage from overloads.⁵¹ In most cases, loads up to 125 percent can be tolerated; however, loads of this size are undesirable, because weighing accuracy usually declines above 100 percent.

Another important aspect of belt loading is uniformity, both in material flow and material symmetry on the belt.^{57,59} In most cases the scale system is capable of operating accurately over a 5-to-1 range. However, a uniform loading is preferable because it prevents the extra demands on the scale caused by weighing constantly-changing amounts. To minimize surges or feed variations, hoppers should be equipped, where possible, with depth-limiting gates.

Weigh belt scale systems multiply product weight by product velocity to arrive at an accurate weight rate for totalization. Since the product velocity is assumed to be identical to the belt speed, the product and belt should be travelling at the same velocity. Thus, the conveyor speed and slope should not exceed that at which material slippage occurs. In addition, double weighing can result from material slippage or water movement in the area of the weighbridge. In a steeply inclined or high velocity system, it is often necessary to locate the scale a considerable distance from the loading point; this should ensure that the material is quiescent when it reaches the scale.^{50,57,60}

Inclined belts place another restriction on weigh scale location. Because of belt tension considerations, measurements are better made near the bottom or tail-end of the conveyer, where the belt tension exerts the least amount of influence on the weighbridge. This is true to some extent for level conveyors, although there is generally no need to limit scale location to the tail-end in this case.^{50,57}

Similarly, scales should not be located near the curved portion of a convex or concave conveyor system, since conditions associated with these systems cause belt tension variations. It is recommended that weigh belt scales be located at least 16 to 20 ft from the base or 40 ft from the top of a convex curve.^{50,57} On a concave curve, the scale should be located at least 40 ft from the point of tangency.^{50,57} If the scale is to be certified, this measurement should be increased to 70 ft.⁵⁸ In addition, scales installed on a concave conveyor must be installed on a section of the conveyor where the belt is straight, and where it makes contact with at least eight idlers (to either side of the scale) throughout the entire loading range.⁵⁸ A good rule-of-thumb for scale location (with regard to conveyor loading and unloading points) is that there should be at least four to five idlers between the scale and either of these points.⁵⁷ One reference suggests at least 20 ft, while another recommends the following distances based on belt speed.^{50,60}

<u>Belt Speed</u>	<u>Scale Distance to Load-out or Load-in</u>
300 fpm	3-4 ft
300-450 fpm	6-8 ft
>450 fpm	9-12 ft

On the other hand, the scale should be no further than 50 ft from the point of loading,⁵⁸ nor should the conveyor have skirtboards anywhere but the loading point.⁵⁹ Finally, the conveyor should be loaded at only one point, thus ensuring constant belt tension.

In any installation where weighing accuracy is important, the weigh scale system should not be applied to a conveyor with a movable tripper. If the scale must be installed on a conveyor with a tripper, then the same rules that govern installation on a concave curved conveyor apply here. The minimum distance rule must be adhered to, with the tripper in its fully-retracted position.⁵⁸

The idlers both on and adjacent to the weighbridge play an important part in belt scale operation and have a major influence on belt scale accuracy. Therefore, the selection of idlers used within the scale area is crucial. This pertains not only to the idler type, but to the idler construction as well. Since idler alignment plays an important role in belt scale operation, all idlers must be manufactured as nearly alike as possible. It is also important that certain types be avoided. The "V" type idlers are not acceptable for a belt scale installation.⁵⁸ If idlers of this type are used in the conveyor, then the four idlers to both sides must be changed to a conventional type of troughing idler. Because of their design and the difficulty in fabrication, five roll deep trough idlers are not normally acceptable either.⁵⁸ Rope or cable support rolls type idlers are also unacceptable. Unless belt loading is constant and accuracy over a limited range is permissible, the idlers that have an offset carry roll or center roll should be avoided also.⁵⁸

The scale mounted idlers must be dimensionally aligned with the three idlers to either side, and the scale should be shimmed up or down as required to achieve immunity to belt tension variations. The weighing idlers and three fixed idlers to either side of the weighing idlers are very closely aligned to achieve as true a weighing platform or section as possible. Vertical misalignment can cause weighing errors in both directions. If the idler(s) of the weighbridge are above the fixed idlers, the scale will weigh light; when they are below the fixed idlers the scale will weigh heavy.⁵⁷ A simple check for this is as follows: On a properly functioning belt scale, a string placed between the fixed or stationary idlers across the weigh idlers should barely touch the weigh idlers. If the weigh idlers are too high, the scale will be delivering a lot less material than the calibration indicated previously. Likewise, if the weigh idlers are too low, it would require an additional amount of material on the belt for any misalignment to be "seen".²⁷ Level weigh decks are essential for proper calibration and performance. Misalignment $\leq 1/32$ in. does not usually affect accuracy; however, a negative misalignment of $1/4$ in. can cause +1 to +2 percent error.^{57,60}

Good idler alignment throughout the entire conveyor is important to assure adequate and true belt tracking under all load conditions. It is extremely important that the belt tracks centrally at all full load

conditions; mistracking can cause belt damage and material spillage.⁶¹ Training idlers for this purpose are normally acceptable if they are located six idlers, or 20 ft, from the weigh scale idlers.^{59,60}

To further promote good belt tracking, the belting construction should have the flexibility necessary to assure contact with all three idler rolls making up each idler assembly as the belt is running empty. This also assures that the material to be weighed is supported by the weighing idler, rather than by the carcass of the belt.⁵⁸

The use of idlers with large troughing angles may cause problems. Not only does the beam (catenary) effect of the belt become more pronounced as the troughing angle increases, but the effect of idler misalignment is amplified as well. Troughing angles of up to 20° are preferred, with 35° acceptable; 45° will rule out a ± 0.5 percent accuracy.⁵⁸

Scale system design makes allowances for several deflections. These are: deflection of the load cells, deflection of the scale carriage and bridge assembly, and deflection of the supporting conveyor structure. It is crucial that these deflections not be excessive. In the manufacture of the scale, the amount of deflection in the load cells and in the carriage and bridge is controlled. The only variable is the deflection of the conveyor itself. Therefore, the conveyor stringers supporting the scale and the four idlers to either side of the scale should be large enough and be adequately supported to limit the relative deflection between the +4 and -4 idlers to no more than $\pm 1/64$ in. No conveyor expansion or stringer splices should be located within this region of the conveyor.⁵⁹

Gravimetric weigh belt scales should be mounted where wind and temperature cannot affect the belt forces or conveyor structure.^{59,60} If the scale is to be subjected to winds in excess of 5 mph,⁵⁸ wind protection must be provided. To accomplish this, a wind-break must extend 20 ft to either side of the scale location.⁵⁶ Because conveyor belts are temperature-sensitive, gravimetric scales generally operate between -10°C and 50°C, while retaining good accuracy; some may even have temperature compensation within the range.⁵⁸

The last point is one of major importance and one that may be a constant problem -- dust build-up. A build-up of dust on the weighbridge can cause a positive zero drift and error,⁶¹ while dust build-up on the

belt causes overweighing.⁵⁹ The belt speed sensor and the idlers themselves may also be affected by accumulation of dust or other stray material.⁵⁹ Regular maintenance (on at the least a daily basis) should include dusting the weighbridge assembly and the speed sensor by using instrument air or by physical brushing.²⁷ Dust problems on the weigh belt itself may be solved by using a belt scraper mechanism,⁵⁹ provided by the manufacturer.

3.1.5 Evaluation Checklist

In summary, the following checklist may be useful as a guide for routine visual examinations of gravimetric weigh belt scales.

- ☐ Belt scale is being operated at between 50 and 90 percent of its rated capacity.
- ☐ Belt loading is uniform in flow and symmetry.
- ☐ No material lumps are larger than 15 percent of belt width.
- ☐ There is no material or water movement in the belt scale area.
- ☐ There is a gravity or tension take-up on a belt longer than 40 ft, and it is located near the head pulley.
- ☐ Unloaded belt runs completely in the idler trough (at correct belt tension).
- ☐ Belt scale is located near the bottom or tail end of the conveyor.
- ☐ Belt scale is acceptable distance from convex or concave curves, load-in and load-out points, skirtboards, and trippers.
- ☐ Belt conveyor does not have "V"-type idlers, five roll deep trough idlers, rope or cable support rolls type idlers, offset carry rolls, or center rolls.
- ☐ Scale mounted idlers and three stationary idlers to either side are dimensionally aligned (within 1/32 in.).
- ☐ Belt tracks centrally at all load conditions.
- ☐ There are no training idlers within six idlers of the scale.
- ☐ Troughing angle of idlers is $\leq 35^\circ$.
- ☐ A windbreak is provided if the scale area is subjected to >5 mph winds.
- ☐ The ambient temperature in the scale area is within the specified operating range for that model.
- ☐ There is no dust build-up on the weighbridge, belt, or speed sensor.

3.2 GRAVIMETRIC WEIGH BELT FEEDERS

Gravimetric weigh belt feeders are somewhat similar to gravimetric weigh belt scales in that they weigh flowing material with a scale applied to a conveyor belt. However, the scales weigh material (usually on its way from one place to another) without concern for the amount delivered per unit of time; the weigh belt feeder, on the other hand, weighs material (on a short belt) in order to deliver a specified amount in a specified time and usually at a constant rate. A weigh belt feeder usually includes feedback controls to achieve this goal.

3.2.1 Operating Principles

Figure 3.2-1 shows a schematic for one type of basic gravimetric weigh belt feeder system. These self-contained units generally include belt drive, scale assembly, and controls.⁵⁰ The material stream enters via the duct at the left, moves across the weighing device on the belt, and is discharged at the opposite end. Since gravimetric weigh feeders use

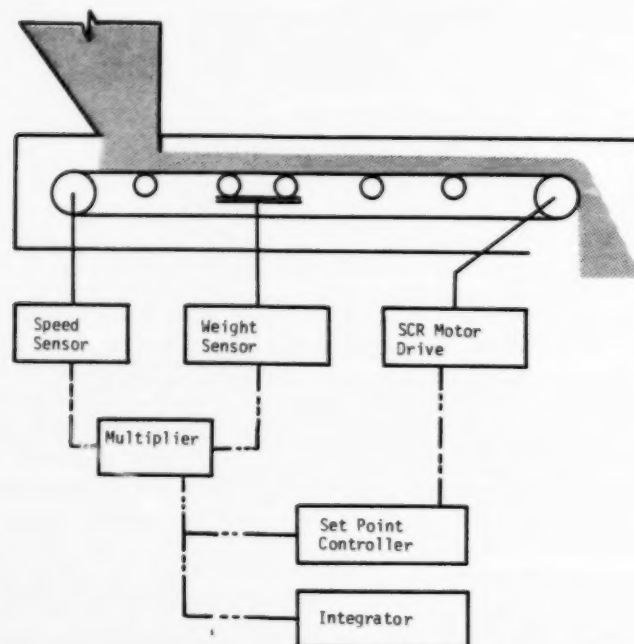


Figure 3.2-1. Basic weigh feeder system.

the same weight-sensing assemblies and techniques as gravimetric weigh scales (in most cases a weighbridge, weigh roll or weigh deck and load cells), these will not be addressed here in detail. However, the controls and their relationship to the operating unit will be discussed.

Figure 3.2-1 illustrates the most accurate, most versatile, and most commonly-used of the three major types of weigh feeder control systems,⁵⁰ sometimes referred to as a rate-control system. In this type of system, the belt speed and the material weight passing over the weigh assembly are constantly monitored. These signals are transmitted to a multiplier, which calculates the true rate of material passing over the scale. This rate is then compared with the user-chosen set rate. If the two rates do not agree, a control signal is sent to a driver controller which then changes the belt speed immediately (before material even reaches the discharge point), to compensate for the deviation. These weigh feeders usually have a manually-controlled fixed gate at the loading point to maintain a constant level of material on the feeder belt.

A less sophisticated type of weigh feeder utilizing weight control is shown in Figure 3.2-2.⁵⁰ In this type of feeder, belt speed remains

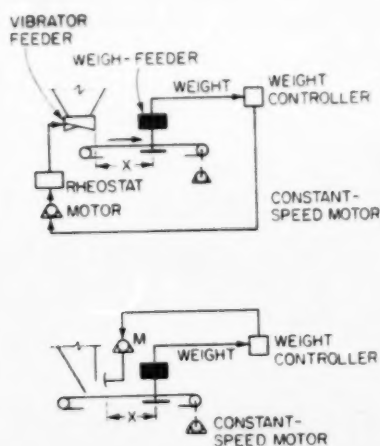


Figure 3.2-2. Two types of weight-control weigh feeders.⁵⁰

constant. The weight signal (lbs/ft) from the weigh assembly is sent to a weight controller, which compares it to the pre-set rate. (Because of the constant belt speed, weight is assumed proportional to rate.) Any deviations are corrected by a signal sent to the weigh feeder feeding device, which then changes the amount of material being loaded onto the belt. These feeding devices may include vibratory feeders, motorized gates, and screw feeders, among others. The main disadvantage in this type of control system is the lag time between the detection of a deviation and its subsequent correction.

The last type of weigh feeder control pertinent to this discussion uses a variable-speed weigh belt to control the rate of flow.⁵⁰ The lbs/ft of material remains constant. The weight sensing idler (usually mechanical), uses a regulator to control a feed control gate. The desired feed rate is obtained by varying the belt speed. This type of control system also has an undesirable lag time between deviation detection and correction.

3.2.2 Accuracy

Because of their shorter belt lengths, weigh feeders tend to be more accurate than comparatively sophisticated weigh belt scales. The literature and vendors cite accuracies of up to ± 0.25 percent^{62,63} of set rate, and at least ± 0.5 percent⁶³, or ± 0.5 percent to ± 1 percent of set rate.⁵⁰

3.2.3 Calibration

Gravimetric weigh belt feeders are calibrated in the same manner as gravimetric weigh belt scales; that is, by using material tests, test chains, and test weights (see Section 3.1.3).

3.2.4 Typical Problems, Errors, and Maintenance

Weigh belt feeders have problems unique to their design, as well as problems similar to those found in the weigh belt scales. As with the weigh belt scales, weigh feeders operate most accurately when their belt load is close to the maximum rating, therefore it is recommended that the feeder systems be operated with at least 50 percent of belt load.⁶⁴

Belt tension can also have a major effect on scale accuracy. On the one hand, tension must be loose enough to permit the belt to take deflection at the weigh platform or roll.²⁷ However, if it is too loose, slippage

can result, causing errors in belt speed sensing at the pulleys or causing a positive error in weighing by exerting a downward force at the weighing area. Preventive design includes (1) putting tension on the return side of the belt to maintain constant tension and avoid sag, and (2) measuring belt speed directly from the belt, not the pulley. One author recommends that the head pulley have a flat rather than crowned design to equalize belt tension and improve accuracy.⁶⁴

A major problem for belt feeders and scales is dust. Dust build-up on the weighbridge, or other horizontal weighing components, or on the belt itself will cause a positive error.⁶¹ Dust build-up on the inside of the belt may also be transferred to the pulleys, making them slip or causing errors in belt speed measurements.⁶⁴ A 0.125-in. build-up on a 14-in. pulley causes a 1.7 percent error in measurements.⁶⁴ Regular maintenance should include the dusting procedures described for belt scales (see Section 3.1.4). A scraper located on the inside of the belt return may also help.⁶⁴ The author mentioned above also recommends that belt speed always be measured at the head pulley; this pulley is the cleanest, while the belt should have a tension here similar to that crossing the weigh area.⁶⁴

Other material related potential problems include material hangups in feeder gates, and dust or spillage that cause jamming or belt mistracking.⁶¹ Jogging is usually used to remedy the later.^{27,61}

Though much less susceptible to problems than the mechanical components, the electronics of weigh feeders may be affected by changes in ambient temperature. Operators must take this into consideration, rechecking the zero, and recalibrating after large changes in temperature.⁶¹

3.2.5 Evaluation Checklist

The following items may be used to perform a visual evaluation of a weigh feeder.

- ☐ Load is at least 50 percent of capacity.
- ☐ Belt is loose enough to permit deflection at weigh area.
- ☐ Belt has tension roll or some other assurance that it does not slip on drive and measurement pulleys.
- ☐ Weigh idler(s) or weighdeck is aligned. (See simple check method in Section 3.1.4.)

- ☐ There is little or no dust build-up on weigh deck, platform, etc.
- ☐ There is no dust build-up on pulleys.
- ☐ Belt is tracking correctly.

3.3 NUCLEAR WEIGH BELT SCALES

Like the gravimetric weigh belt scale systems, nuclear weigh belt scale systems are not generally used as direct kiln feed rate monitors. Instead, they are usually part of a larger materials balance check system. However, the nuclear monitor as described below can be used to measure mass flow in material transfer systems other than a conveyor belt.⁶⁵ It has been applied directly to proportioning screw feeders, and to the combination system used for kiln feed rate monitoring and control.⁶⁶

3.3.1 Operating Principles

These types of scales are normally constructed from a "C"- or "A"-type frame that houses the source and detector (see Figure 3.3-1 and 3.3-2). The upper portion of the frame usually contains the source and shield assembly, while the bottom arm contains the detector. (In some units these locations are reversed.) The weigh scale operates on the gamma ray absorption principle, in which a radioactive source (usually cesium 137) emits gamma rays that are projected through the material on the belt and the belt itself, to the detector. The rays are absorbed in proportion to the mass on the belt, according to the following equation:⁶⁶

$$I = I_0 \exp \left(\frac{-\mu L}{W} \right)$$

Where: I = Radiation (Cs 137) transmitted to detector
 I_0 = Radiation (Cs 137) transmitted to detector with empty belt
 μ = Radiation absorption coefficient
 L = Loading on belt in mass/unit belt length
 W = Belt width

Energy not absorbed by the material on the belt is transmitted to the detector, which generates a proportional electrical signal. As with gravimetric scales, this loading signal is combined with a belt speed transducer signal to obtain a mass/time signal. This signal is then fed into a totalizer, yielding the total mass that has passed through the belt system.

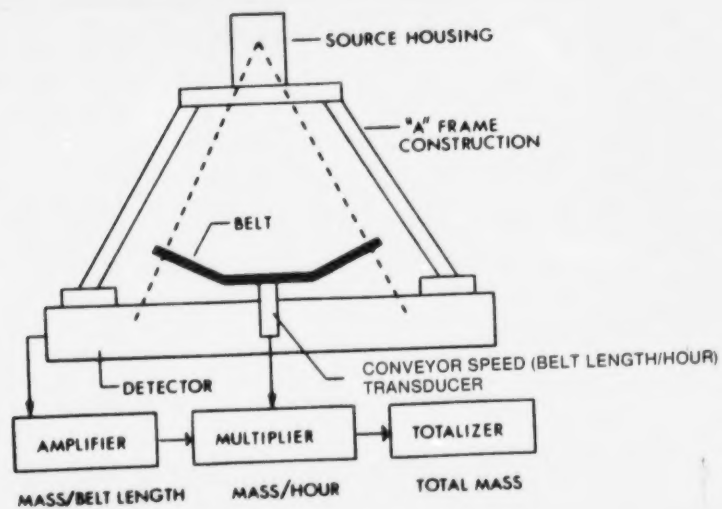


Figure 3.3-1. Nuclear weigh belt scale with A-frame.⁶⁶

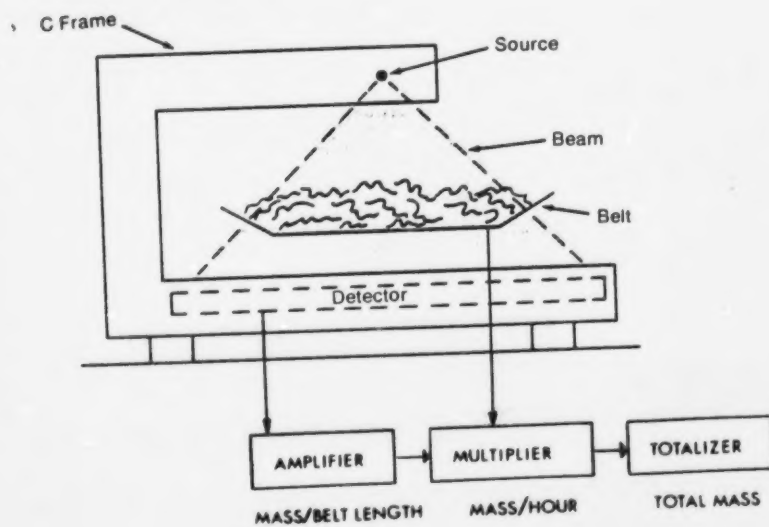


Figure 3.3-2. Nuclear weigh belt scale with C-frame.

The C- or A- frame that makes up the nuclear weigh belt scale slips around the conveyor and bolts to the conveyor frame. The unit can be installed at any point in the process stream, and can be used on belt conveyors, screw conveyors, drag conveyors, apron conveyors, and vibratory conveyors. The unit is ideally suited for retrofitting an existing conveyor system.

There are no reported radiation hazards in scale operation when industrial safety practices are followed. Radiation levels are below 5 MR/hr, one ft from any accessible surface except directly within the measurement beam;⁶⁷ however, a license is usually required to operate the scale in the U.S.A.

The operating temperature range is relatively large at minus 40°F to 140°F.⁶⁷

3.3.2 Accuracy

Stated accuracy varies between ± 0.75 percent and ± 1 percent depending upon application and manufacturer.^{66,67,68} Discussions with plant operators who use these instruments have indicated typical accuracies of 1 percent with source drift occasionally causing errors as great as 3 percent.^{19,27}

3.3.3 Calibration

The two principal methods of nuclear weigh belt scale calibration are the dynamic material test procedure and the static calibration plate (or material) procedure. Most nuclear scale manufacturers recommend conducting a material test for the initial calibration. Recalibration is then performed on a monthly basis using the calibration plate that is usually supplied with the weigh scale.⁶⁹

3.3.3.1 Material Test

In the dynamic material test calibration, the belt is first run empty and the zero set on the control box. Once the belt scale is zeroed out on an empty belt, a 15 to 30 minute sample is run through the nuclear weigh belt monitor into a vessel or truck which can then be precisely weighed. This weight is divided by the running time to obtain an average mass/time rate. This value is then related to the gauge reading, and the result entered into the control box. For proper calibration, the belt must be loaded between 70 and 100 percent of full scale.²⁷

3.3.3.2 Calibration Plate

In a static calibration, either a calibration plate or a known amount of material is placed within the detection beam of the nuclear weight belt monitor. The calibration plate provides a convenient, time-saving method of recalibration. A plate (cast iron or mild steel) is positioned between the source monitor and detector while the belt is operating and empty. The plate usually simulates a known belt loading between 70 and 100 percent of full scale. (This known value is usually confirmed during the initial material test and marked on the calibration plate.) The plate provides a fixed reference point in later calibration procedures, regardless of changes in source, detector, or electronics.^{27,69}

Another method of static calibration involves placing a known amount of material (representing 70 to 100 percent of scale value) on a stationary weigh belt between the source and the detector. A dummy belt speed signal is input to the totalizer to simulate actual operating conditions. Using the resultant scale values for mass flow and totalizer flow, the proper calibration can be determined.²⁷

3.3.4 Typical Problems, Errors and Maintenance

The major advantage of the nuclear scale is that it does not come in contact with any moving parts of the belt conveyor, such as the belt, idlers, or the moving load. Therefore many of the conditions that can influence accuracy of the load cell type belt scale -- such as adequate loading, belt tracking, scale location, trippers, tension or gravity take-ups, conveyor support, cable or rope conveyors, steel cable supported conveyors, idler type, idler alignment, troughing idler angles, and wind break -- have no effect on the nuclear scale. Temperature also has relatively little influence.

Factors which affect the accuracy of the nuclear weigh belt are limited almost exclusively to the characteristics of the material being conveyed. These factors include material type and characteristic changes, slippage, load considerations, and extraneous material build-up.

As indicated in Figure 3.3-3, the radiation received at the nuclear scale detector and the resulting output signal are inversely proportional to the mass on the conveyor. To maintain the operational accuracy of

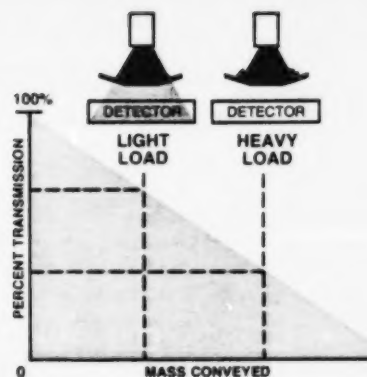


Figure 3.3-3. Output signal vs. conveyor loading.⁶⁶

± 0.5 percent, a minimum load of about 2.7 lb/ft^2 is required on the belt. This results in a radiation change at the detector of 5 percent; lower belt loadings reduce repeatability because of the lower signal-to-noise ratios.⁶⁶ Ideally, belt load should remain between 70 and 100 percent of full load to minimize errors due to system response time and large profile changes.⁶⁶ In addition, belt loadings which constantly vary more than 30 percent will most likely affect accuracy.⁷⁰ Nuclear scales have one disadvantage in that their maximum capacity per belt area (generally about $2 \text{ lbs/ft/in. width}$) is less than that for a comparable gravimetric scale.⁵⁸

As mentioned previously, the nuclear belt scale is sensitive to large variations in product profile. The product profile varies with the average particle size of the product because changes in particle size are usually related to changes in bulk density. Varying bulk densities can degrade accuracy from ± 0.5 to ± 3 percent.⁷⁰ In addition, product lumps greater than 15 percent of the belt width will also affect readings.⁷⁰

Understandably, nuclear scales cannot weigh more than one material simultaneously. Different materials have different chemical and physical characteristics, and therefore may have different radiation absorption characteristics.⁷⁰ Thus, these scales must be recalibrated for material changes. Along these same lines, changes in material moisture

content can affect accuracy. Errors are caused by the difference in radiation absorption as water displaces the material.⁷⁰ A large change in moisture content can affect accuracy by as much as ± 5 percent.⁶⁶

As is true for other belt scale installations, material slippage in the area of a nuclear scale will cause weighing errors. Due to material movement, the detector might potentially "see" more or less material than is actually present. Scale location considerations on this account are the same as those outlined for gravimetric weigh belt scales (Section 3.1.4).

Because in a nuclear scale system, radiation passes from the source through the material, belt, and detector frame, material build-up on the detector portion of the nuclear scale will be detected as material on the conveyor belt. Likewise, material build-up on the belt (material not removed from the belt at the load-out point, especially true with sticky materials) will also be detected. Both types of material build-up can cause positive errors in measurements in direct proportion to the amount of build-up present. Build-up problems on the belt can usually be solved by installing a belt scraper, while build-up on the detector can be prevented by regular maintenance utilizing instrument air, brushing, or water jets to remove the material. If a constant build-up remains, the resultant error may be zeroed out by recalibration.⁶⁶

Analogous to belt build-up, water running down the belt into the scale area can also cause significant positive error.⁶⁶ If the scale location could potentially permit water to collect on the belt, operators should check regularly to see that water does not run down the belt into the scale area.

3.3.5 Evaluation Checklist

The previous discussion suggests the following checklist for nuclear weigh belt scale evaluation.

- ☐ Belt loading is between 70 and 100 percent of rated capacity (or at least greater than 2.7 lb/ft²).
- ☐ Belt loading does not vary by more than 30 percent on a regular basis.
- ☐ Product profile does not appear to change significantly.
- ☐ Product does not include lumps larger than 15 percent of belt width.
- ☐ Scale is not used to weigh more than one material or material bulk density without recalibration.

- ☐ There is no material slippage in the vicinity of the scale.
- ☐ There is no material build-up on the detector.
- ☐ There is no material build-up on the belt.
- ☐ There is no water running on the belt in the weighing area.

3.4 IMPACT FLOWMETERS

This type of process monitor is designed for use as an in-line flowmeter for measuring solids, liquids, and slurries. In the portland cement and lime industries, it finds typical application in the weight measurement of solids less than 3 in. in diameter. Impact flowmeters make material flow measurements by sensing the force produced by the material as it free falls (by gravity) onto a sensing device. Two types of sensing devices are currently used in impact flowmeters: the impaction plate and the impaction cone. The former device is used in the majority of installations in the lime and cement industries, therefore the following discussion will focus almost exclusively on the impaction plate type of flowmeter.

3.4.1 Operating Principles

The impaction plate flowmeter consists of three major component systems: (1) the impaction plate and associated sensing components, (2) the flowguide assembly, and (3) the electronic components including the transformer, amplifier, and totalizer. During impaction plate flowmeter operation, the material to be measured free falls from a prefeeder down the flowguides. As this free falling material impacts the sensing plate, it imparts a force on the plate.

This force can be resolved into vector components (see Figure 3.4-1) which yield a vertical force vector downward (F_v , due to the force of gravity) and a horizontal force vector perpendicular to the direction of flow (F_h , proportional to the instantaneous flowrate). The impaction plate technique measures the horizontal force vector by using a mechanical displacement mechanism to convert the force into an electrical signal. F_h acts through the impaction plate and support arm, against the spring, and is converted into horizontal movement (see Figure 3.4-1). The transients are smoothed out with a viscous fluid; a transformer then converts the movement into an electrical signal. The horizontal force (F_h) and the movement are proportional to flowrate; voltage is proportional to movement, making the voltage from the transformer directly proportional to the flowrate over the plate.

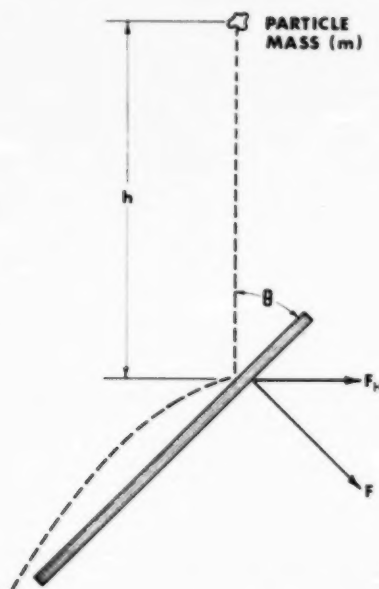


Figure 3.4-1. Impaction plate.⁷¹

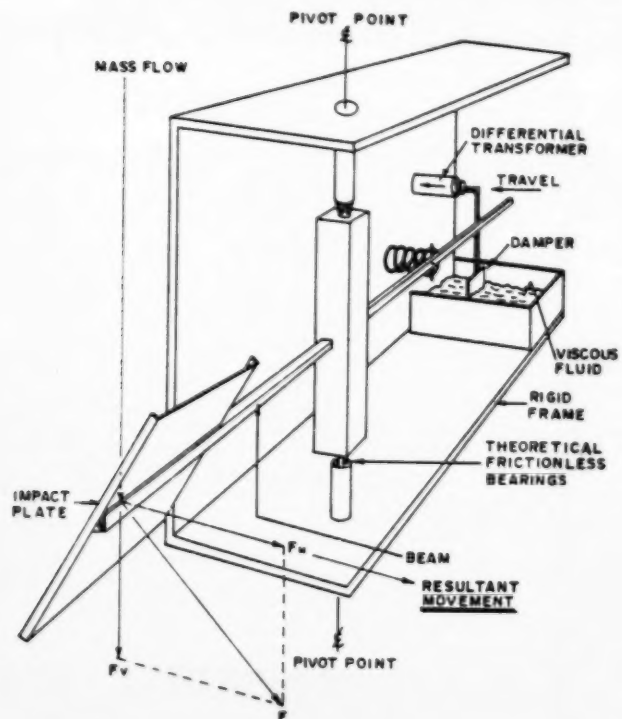


Figure 3.4-2. Mechanical components of the impaction plate flowmeter.⁷¹

Finally, the signal from the transformer is related to the remainder of the electronics package. This package contains a power amplifier that increases the signal, and a totalizer that integrates the rate of flow over a period of time to determine totalized flow (see Figure 3.4-3).

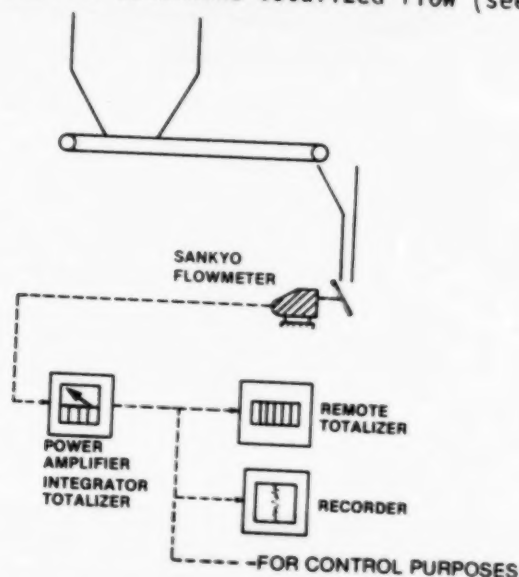


Figure 3.4-3. Example of impact flowmeter instrumentation system.⁷¹

The flowguide assembly directs the material flow onto the impaction plate ensuring a constant pattern thereon (this is an important part of the impact flowmeter). Flowguide assemblies may be manufactured from numerous materials. In the cement and lime industries these assemblies may include screw or rotary type feeders, or may simply consist of a chute or pipe designed to deliver uniform material flow.

Impact flowmeters with an impaction-cone sensing device are referred to as solids flow transmitters by their manufacturer.⁷² Although suitable for cement and lime applications, they are less common than the impaction plate device, and are not being produced at the present time. They operate using the same general principle, with the exception that the force of impact measured is a downward rather than horizontal force on the sensor cone (see Figure 3.4-4). The sensor is mounted on precision springs; its vertical movement is conveyed by transfer rod to a transducer, which converts the movement into an output signal. This signal varies directly with the mass flow rate.

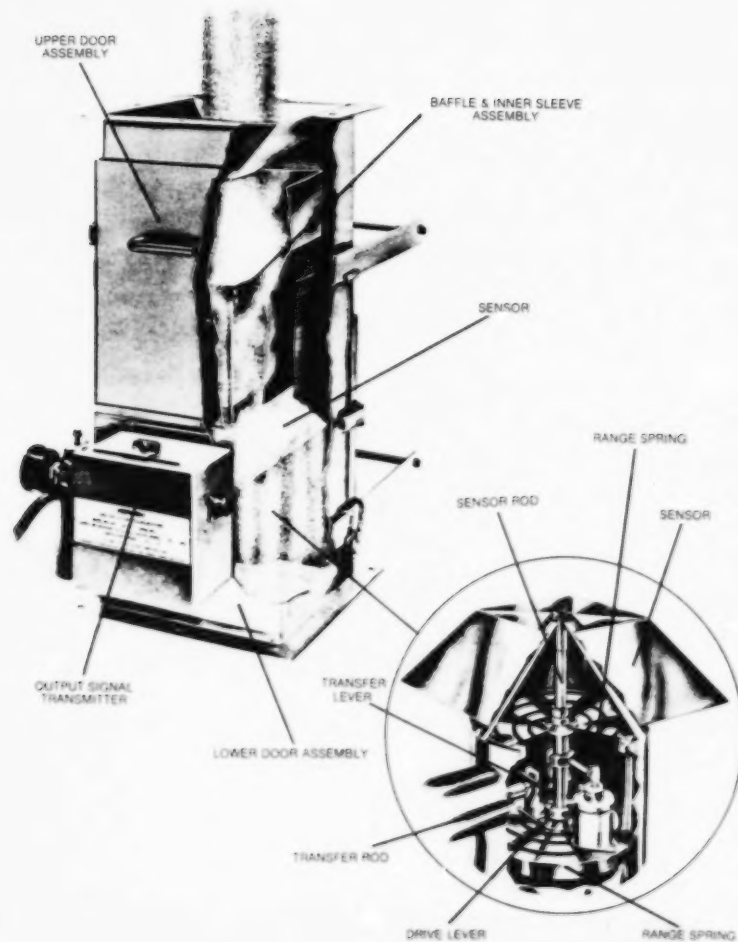


Figure 3.4-4. Impact flowmeter with cone-type sensor.⁷²

3.4.2 Accuracy

Impact flowmeters are quite accurate; manufacturers generally claim 0.5 percent of full scale, and comments from plant instrument operators confirm this.^{27,71,72}

3.4.3 Calibration

As with the weigh belt scales and the nuclear scales discussed previously, initial calibration of an impaction plate flowmeter is usually accomplished by using a material test and subsequent recalibration uses a static test "weight" (Figure 3.4-5). The initial material test calibration is recommended upon installation, with recalibrations performed at monthly intervals (more often if required by special circumstances or if warranted by inconsistent readings).²⁷

Some of the newer flowmeter system installations may have a third calibration check that utilizes a bin-load cell weighing system,¹⁸ described in Section 3.4.3.3.

3.4.3.1 Material Test⁷³

In an initial calibration, the flowmeter reading or registration is compared to the actual measured flow and adjusted to agree with the desired registration or flow factor.* To achieve this, sample material is run over the impaction plate, then caught and weighed. This sample should have at least a 3-min duration at a rate of 50 percent or more of the full scale flow rate. The weight of the material is then compared with the count on the totalizer to arrive at the measured flow factor of weight per count (weight of sample/ totalizer count).

Next, a test weight is attached to the plate mechanism by a string over the calibration pulley. This weight should be approximately 150 grams per ton per hour of the flowmeter's full scale flow rate and must give a reading of at least 50 percent on the indicator.** At this point, the ratio of the previously measured flow factor to the desired registration or flow factor (e.g. 10 lbs/ totalizer count) is multiplied by the indicator reading to yield a new indicator setting. The 'span' control is adjusted to the new setting. Thus,

$$\text{new indicator setting} = \text{indicator reading} \times \frac{\text{measured flow factor}}{\text{desired flow factor}}$$

* On the Sankyo Impact Inline Flowmeter,²⁷ one of the most commonly used, the totalizer reading or registration is expressed in 'counts'. When the flowmeter is calibrated at installation, the user selects a desired registration (such as 10 lbs per totalizer count), for which the flowmeter will be calibrated.

** The indicator displays percentage of span.

3.4.3.2 Static Test Weight Recalibration⁷³

A static test weight recalibration is accomplished simply by attaching the same test weight and confirming that the indicator reading equals the reading determined previously.

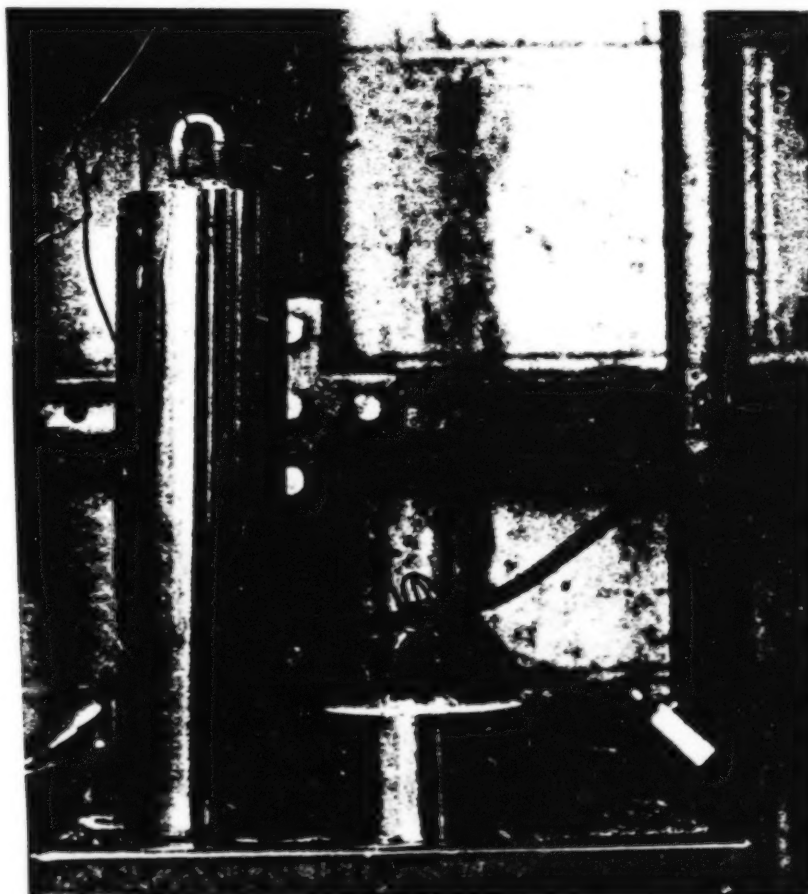


Figure 3.4-5. Static test weights.

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3.4.3.3 Bin-Load Cell Calibration Check¹⁸

This type of calibration check is simply a variation on the material test; however, it is easier to perform and hence can be used for routine recalibration. It can be performed with a system where a "calibrated" holding bin is located prior to the flowmeter. Holding bins are "calibrated" using load cells which can measure the loss in weight of material in the bin over a period of time. Thus, to check the flowmeter calibration, a measured amount of material from the holding bin is allowed to pass through flowmeter. The known value of material from the bin is then compared to the reading obtained from the totalizer.

3.4.4 Typical Problems, Errors, and Maintenance

The impaction plate flowmeter is a relatively simple monitoring device, with essentially no moving parts. Compared to other continuous weighing devices there are relatively few points in this type of process monitor which will cause errors in readings or problems in operation.

Probably the most important point to remember in preventing errors in impaction plate flowmeter readings is that the plate and meter be properly installed and leveled.²⁷ The pivot upon which the beam and support moves must be vertical. Otherwise, particle build-up on the plate, beam, and other surfaces can result in a force that will be "seen" by the flowmeter as part of the measured horizontal force (F_h), thus causing a shift in the zero point (known as zero drift). One operator has reported a 10 percent error in readings caused by an improperly leveled flowmeter.²⁷ A simple check to ensure that the pivot point is vertical involves hanging a test weight directly on the sensing plate. If the indicator reading changes when the test weight is added, a leveling adjustment is required.²⁷

Another circumstance which can result in an extraneous horizontal force on the beam is build-up of material at the point of impingement on the plate; this may cause erroneous readings due to interference with the transfer of momentum from the free-falling material to the plate.⁷¹ Material accumulating outside of this area usually will not cause zero drift because it adds no horizontal component to the force (unless the flowmeter is not level). In cases where build-up is a major problem, an optional rapper plate can be installed or the impaction plate can be changed to one coated with Teflon® or a similar compound. Some flowmeter models provide doors for observation and maintenance of plates. A typical installation is shown in Figure 3.4-6.

Because a change in the energy-absorbing characteristics of the material measured can affect flowmeter accuracy, recalibration should be conducted if there is a change in material type. Changes in particle shape or hardness are the factors which determine the energy absorption; size, density, and moisture usually have little effect. (Some recent flowmeter systems include calibration compensation switches which can be set for additional materials; thus the monitor may be used consecutively

for more than one material, providing the compensation switch has been calibrated for that material.)^{71,74}

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Figure 3.4-6. Typical impact plate flowmeter installation.

The velocity and angle of the material striking the plate can also cause inaccurate readings.⁷⁴ Velocity and angle are usually controlled by properly designed flowguides and equipment arrangement. Flowguide assemblies also ensure that the falling material is directed onto the center of the plate.^{27,74} These flowguides are usually properly designed by the manufacturer, but caution must be taken when using the same flowguide for a different material or a substantially different flowrate.

The last item which can affect readings is airflow against the plate. In this case a horizontal force may develop, and zero drift be introduced. In such instances, airflow must be eliminated or at least directed away from the plate.⁷⁴

3.4.5 Evaluation Checklist

The previous section suggests the following visual inspection points to be used in routine impact flowmeter evaluation.

- ☐ The material flow impacts on the center of the sensing plate or cone.
- ☐ Flowmeter is used for only one material (unless material change calibration compensation is built into the electronics).
- ☐ There is no appreciable buildup of dust in the impingement area of the impaction plate (or cone).
- ☐ There is no airflow against the plate (or cone). Note: Most of these devices are enclosed so this may not be a problem.
- ☐ Material measured by the flowmeter does not change in particle shape or hardness.
- ☐ Plant maintenance procedures for flowmeter include ensuring that it is kept properly leveled.
- ☐ The flowguide assembly is the proper one for current material and flowrate.

3.5 PNEUMATIC WEIGH FEEDING SYSTEMS

Polysius Corporation, a major design/construction firm for cement plants, recently installed pneumatic weigh feeding systems in five U.S. plants. The system is marketed under the name POLDOS®.28,29,75,76

A schematic of the POLDOS® system is shown in Figure 3.5-1.76 Raw meal is fed from the homogenizing silos through a set of control valves to a bucket elevator. The meal is dumped into a calibration tank mounted on load cells, then metered out of this tank by a control valve. The meal passes down an airslide to the pneumatic conveyor, which transports the material to the top of the preheater. The mass flow from the pneumatic conveyor is linearly related to the floor pressure below the pneumatic conveyor (AEROPOL®) aeration surface. The pressure is converted by a transducer into an electrical control signal for the main solids flow valve located under the calibration bin. By using the pressure level as an indicator of flow, it is possible to eliminate the weigh belt feeder which used to be installed below the calibration bin.

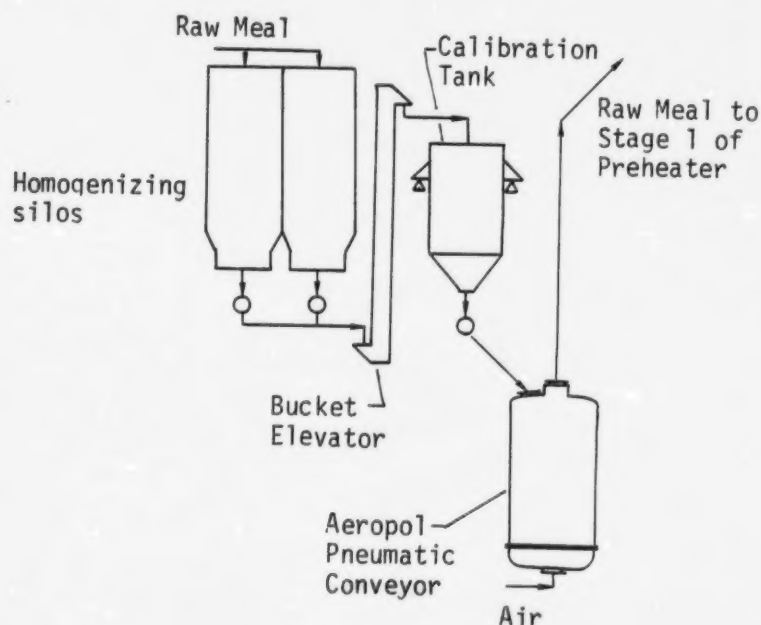


Figure 3.5-1. POLDOS® pneumatic weigh feeding system schematic.

Polysius claims an accuracy of better than 1 percent which is equivalent to the accuracy claimed for conventional weigh feeding systems.²⁹ The POLDOS® system is calibrated by interrupting the material flow to the calibration bin and allowing the raw meal to empty out for a period of time.^{75,76} The difference in the calibration bin weight before and after the test is compared with the pressure value. A number of tests at different feeding rates are used to generate the complete calibration curve. Examples of these calibration curves are available in references 75 and 76. As part of the overall calibration procedure, the load cells on the calibration bin are checked by hanging various weights on the side of the bin.²⁹

Polysius reports no serious problems with the operation of the POLDOS® system,²⁹ which is entirely enclosed and has no external mechanical parts which could be checked. Because of this, agency observers must rely strictly on plant calibration data.

3.6 PLUNGER TYPE FEEDERS

Lime plants with rotary kilns and preheater towers generally use a plunger type feeding mechanism to deliver the hot limestone feed to the kiln.^{32,34,38,47,49} By controlling the length of the stroke and the frequency of operation, it is possible to achieve the desired volumetric feed rate.^{32,49} Depending on the design of the preheater, the system may be equipped with 4 to 18 of these feeders.^{32,34,47,49}

Calibration of the feeders can be accomplished in a manner analogous to that used to calibrate the impaction flow monitors and the POLDOS® system. The stone feed bin can be mounted on load cells and emptied over a period of time in order to relate the plunger operation to the mass of material fed. High- and low-level indicators in the stone bin could be used in lieu of the load cells. They can also be calibrated using material balance checks.

Since the feeding mechanisms are mounted internally on most types of preheaters, it is impossible for any agency observer to evaluate their performance. The kiln rotational rate may provide one index of the feed rate since the feeding system is synchronized with the kiln speed.

3.7 MAGNETIC FLOWMETERS

Because of their ability to measure volumetric flows of abrasive slurries, magnetic flowmeters find prevalent use for kiln feed rate monitoring in the wet process cement industry. These flowmeters measure, over a period of time, the flowrate and total flow of the blended raw material slurry sent into the kiln. This flowrate can be converted to dry raw material mass flowrate by taking into account slurry density (which remains reasonably constant). One plant uses a magnetic flowmeter in conjunction with a density meter.^{4,77} The density meter is generally a nuclear density gauge that measures slurry weight per gallon. A typical magnetic flowmeter system is shown in Figure 3.7-1.

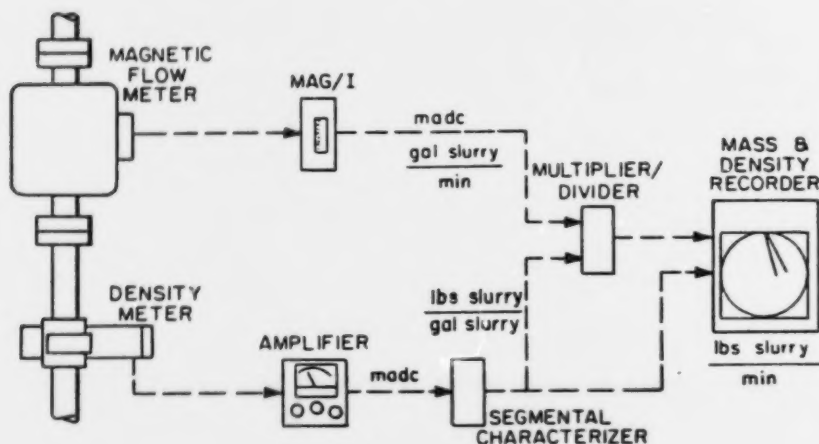


Figure 3.7-1. Magnetic flowmeter/nuclear density gauge system for mass flow measurement.⁷⁷

3.7.1 Operating Principles

Magnetic flowmeter operation is based on Faraday's law of electromagnetic induction. This law states that the movement of a conductor at a right angle to a magnetic field will induce a voltage within the conductor, and that the magnitude of this voltage will be directly proportional to the relative velocity between the conductor and the magnetic field. In the case of the magnetic flowmeter, the conductor is the liquid or slurry being measured, which itself must have a minimal amount of conductivity. The magnetic field is supplied by electrical coils external to the conductor

flow. Figures 3.7-2 and 3.7-3 illustrate the two main components of the magnetic flowmeter, the flowtube and the flow transmitter.

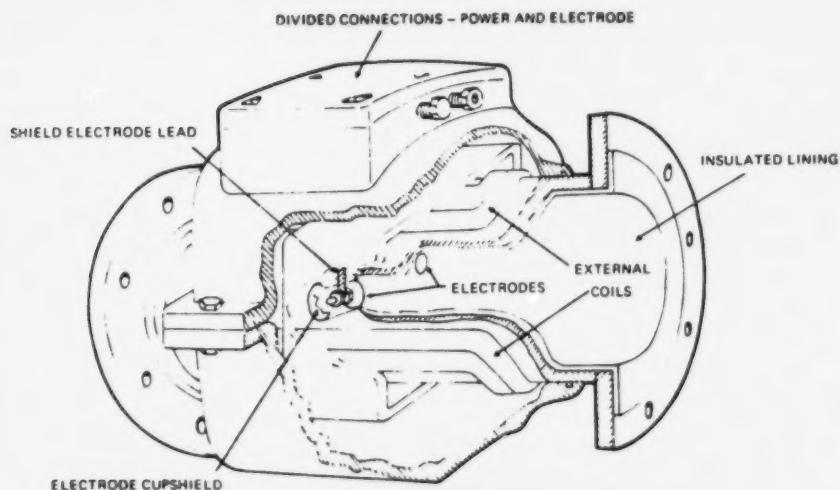


Figure 3.7-2. Magnetic flowmeter flowtube.^{7d}

The process liquid or slurry moves through the flowtube (in either direction), while the magnetic field at right angles to the flow is set up by the coils located on either side of the flowtube. Electrodes mounted in the wall of the flowtube detect the voltage produced by the movement of the conductor perpendicular to the field (see Figure 3.7-4). The voltage, which is directly proportional to conductor velocity, is transferred to the transmitter at either a close or remote location by shielded cable. The voltage is amplified by the transmitter, then converted to flowrate; it can then be recorded, totalized, or used for control purposes.

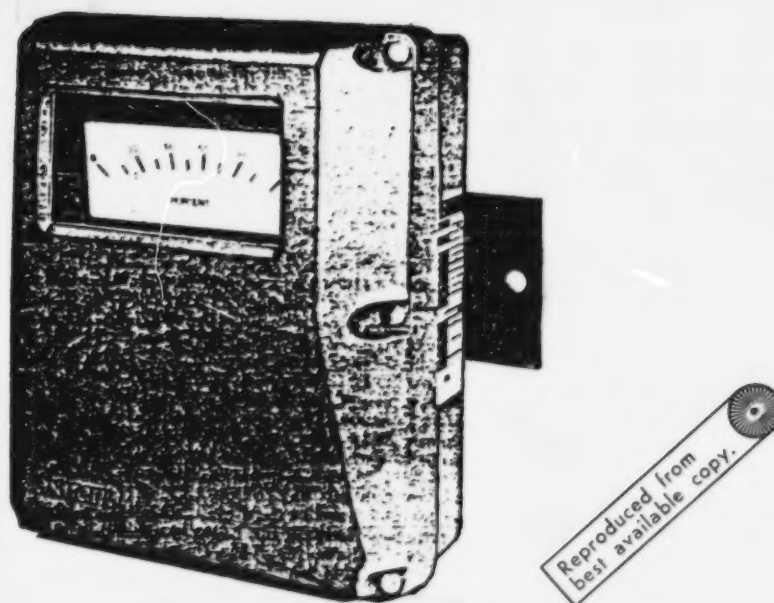


Figure 3.7-3. Magnetic flowmeter transmitter.⁷⁸

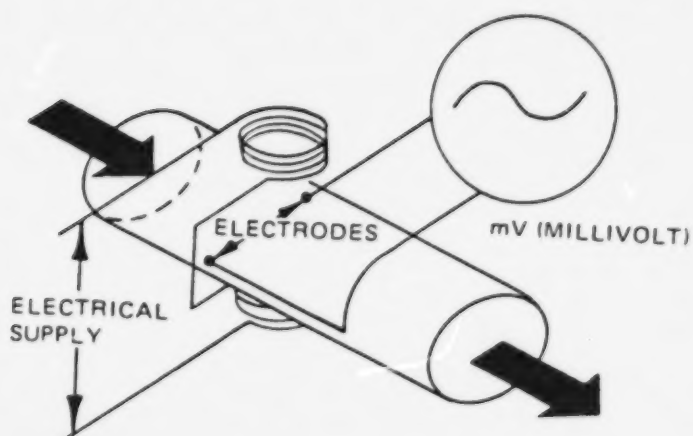


Figure 3.7-4. Schematic of magnetic flowmeter operation.⁷⁸

The lining and electrode materials used in magnetic flowmeters vary according to application, and are usually recommended by the manufacturer. A typical flowtube lining for cement slurry is polyurethane, used because of its high resistance to abrasion.⁷⁹ Stainless steel is the material of choice for electrodes in this application. This is due to its reasonable cost and the fact that a material with higher corrosion resistance is not required.⁷⁹

3.7.2 Accuracy

Magnetic flowmeter accuracy differs slightly from manufacturer to manufacturer, but many claim ± 1 percent of full scale or better.⁸⁰ Some manufacturers claim accuracies of ± 1 percent of actual flow,⁷⁹ and others go as low as ± 0.5 percent of full scale.⁸¹

3.7.3 Calibration

Magnetic flowmeter calibration is almost always performed using an electrical simulator;⁷⁹ however, in cases where maximum accuracy is required, a comprehensive water calibration that uses a calibration rig is essential.⁸² The simulator is connected to the electrode wires in the transmitter, and simulates normal conductor fluid voltages through the flowtube for different flow velocities.⁷⁹ The transmitter is checked to ensure that these readings agree with the simulator readings. Because this type of calibration requires that the process to be shut down, and because magnetic flowmeters seldom, if ever, drift from calibration, these flowmeters are usually calibrated only once, at the time of installation.⁷⁹

3.7.4 Typical Problems, Errors, and Maintenance

Since they have no moving parts and present no obstruction to the fluid flow, magnetic flowmeters have relatively few problems. Additionally, they are not affected by parameter changes that can influence other types of flowmeters; these parameters include fluid density, fluid temperature, pressure, and fluid conductivity above the minimum required for operation. Nevertheless, some points regarding meter installation and operation deserve consideration.

To ensure accurate readings, flowmeters must stay full of fluid at all times; entrained gases are measured as liquids and can cause reading errors.^{78,79} Proper sizing, however, can help prevent this. Generally,

the flowtubes can be installed with the fluid flow in any direction. But in the case of slurries (e.g. cement), flowtubes should be installed with the flow upward.⁷⁸ This guarantees that they will always be full and, in addition, aids in equalizing wear from abrasive particles and reducing the chances of liner coating problems caused when solids tend to migrate downward.

Also an important factor to consider when installing a flowmeter for use with a slurry is that the flowtube should be located upstream of flow disturbances;⁸³ this will decrease wear. It is recommended that the tube be made accessible for cleaning purposes.⁸³

Electrical considerations for installation include proper grounding of the flowtube, since stray current and voltage can significantly affect meter readings.^{78,83} Subsequent maintenance should include routine checks for corrosion of grounding connections, which may include both grounding straps and pipe flanges (these are especially susceptible).⁸³

Compensation for voltage supply variations to the flowtube coils must be made at the transmitter.⁸³ Ideally, transmitter power should come directly off the flowtube, so that the transmitter "sees" the same voltage and can adjust accordingly.⁸⁰ In achieving this set-up, electrode signal leads should be run separately from power wire.

In the case of "dirty" liquids such as slurries, a coating can be deposited on the inside of the flowtube. Errors in readings can result if this coating does not have the same conductivity as the rest of the fluid. A higher conductivity will result in readings lower than actual; a lower conductivity can cause readings greater than actual.⁸³

To prevent the build-up of solids that cause coating, higher fluid velocities are preferable. However, since some slurries are abrasive and higher velocities compound this problem, a compromise must be made. Manufacturers recommend velocities less than 10 ft/sec^{78,80} to reduce abrasion, but greater than 4-6 ft/sec⁸⁰ or 6-8 ft/sec⁷⁸ to prevent particle build-up.

Finally, although normal changes in process fluid temperature will not affect magnetic flowmeter readings, excessively high or low temperatures can cause flowtube construction materials to deteriorate, or can cause flux field changes which could affect the value of the induced

voltage.⁷⁸ Depending on the flowtube or liner material, manufacturers generally recommend maximum operating temperatures of 100°F to 360°F.⁸⁰

3.7.5 Evaluation Checklist

A magnetic flow monitor is usually not subject to serious operational problems. However, if data confirmation is desirable, the following checklist may be of assistance. Since the instrument is totally enclosed, the extent to which proper operation can be checked is quite limited.

- ☐ Check the monitor installation to confirm that the site is free of serious flow disturbances.
- ☐ Confirm that instrument is properly grounded, and grounding is free of corrosion, by visually checking ground strap or area.
- ☐ Compare instrument reading to kiln rotational speed.

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APPENDIX A. CALCULATING THE KILN FEED RATE
FROM THE CLINKER OR CEMENT PRODUCTION RATE

The clinker production rate and the cement production rate are related to the kiln raw material feed rate. Therefore, these two operating rates can be used to calculate the kiln feed rate.

Figure A-1 shows the relationship in cement production between the kiln feed, clinker, and cement with respect to process stream gains and losses. To mathematically convert between clinker production rate, cement production rate, and kiln feed rate, it is necessary to know the magnitude of these gains and losses, each of which is described below.

- o the moisture evolved in the kiln - is approximately the same as the total moisture content of the kiln feed, it can be estimated by multiplying the percentage moisture times the feed through the kiln. In the dry process, it is usually one-half to one percent and in the wet process about thirty eight percent of the mass of the feed.
- o the carbon dioxide (CO₂) evolved in the kiln - is a result of the conversion (calcination) of the calcium carbonate (CaCO₃) and magnesium carbonate (MgCO₃) in the kiln feed to CaO and MgO, respectively. Assuming that all of the carbonates present are calcined, the CO₂ evolved may be calculated by multiplying the weight percent of CO₂ in each carbonate compound times the weight percent of that carbonate compound in the kiln feed times the total kiln feed and summing the two products.
- o the dust emissions from the kiln (not recycled) - is a parameter usually expressed as a percentage of the kiln feed.
- o the gypsum added to the clinker to make cement - is a parameter usually expressed as a percentage of the final product, cement.

The values discussed above are different for each cement plant and may vary slightly from day to day at the same plant.* These values or the

*On a dry basis, the typical ratio is 1.6 pounds of raw meal kiln feed per pound of clinker produced.

values used to determine them, are generally available from plant operations personnel. In fact, many facilities routinely perform calculations similar to the ones to be presented below as a material balance check on their own process.

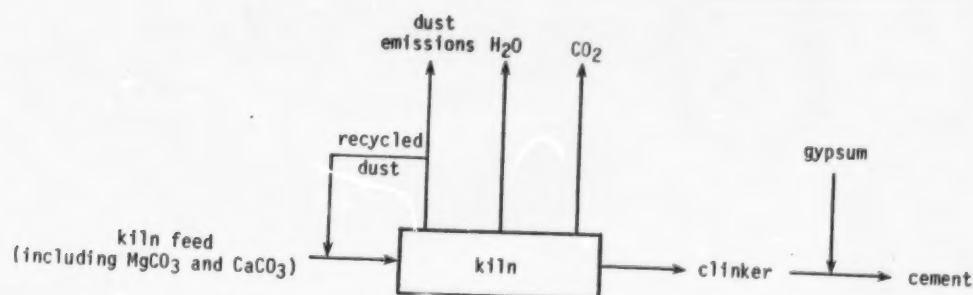


Figure A-1. Cement process stream gains and losses.

The following equations may be used to convert from clinker production rate or cement production rate to kiln feed rate (or any other conversion between any two of these rates).

- K = kiln feed rate (mass/hr)
- C = clinker production rate (mass/hr)
- P = cement production rate (mass/hr)
- M = moisture content of kiln feed (expressed as decimal percentage)
- W_{mg} = weight fraction of $MgCO_3$ in kiln feed (expressed as decimal percentage)
- 0.52 = weight fraction of CO_2 in $MgCO_3$
- W_{ca} = weight fraction of $CaCO_3$ in kiln feed (expressed as decimal percentage)
- 0.46 = weight fraction of CO_2 in $CaCO_3$
- D = kiln dust not recycled (expressed as decimal percentage of kiln feed)
- G = gypsum content of cement (expressed as decimal percentage)

To convert from kiln feed rate to clinker production rate:

$$C = K[1 - (M + 0.52 W_{mg} + 0.46 W_{ca} + D)] \quad \text{Equation A-1}$$

To convert from clinker production rate to kiln feed rate:

$$K = C / [1 - (M + 0.52 W_{mg} + 0.46 W_{ca} + D)] \quad \text{Equation A-2}$$

To convert from cement production rate to kiln feed rate:

$$K = (1 - G) P / [1 - (M + 0.52 W_{mg} + 0.46 W_{ca} + D)] \quad \text{Equation A-3}$$